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Lieutenant, United States Navy
B.S., Oregon State University, 1959

Submitted in partial fulfillment
of the requirements for the degree of

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ABSTRACT

This study was conducted to establish the performance parameters of a radial in-flow, dual discharge turbine and to determine the effect of axial clearance on these parameters. The results of the tests can be utilized for design improvements and for predicting off-design operating conditions.

The air tests of the turbine were made at several total-to-static pressure ratios. The study presents data obtained from measured rotor discharge flow conditions as well as overall turbine conditions. The test turbine is installed at the Propulsion Laboratory of the Naval Postgraduate School, Monterey, California.

The following pages should be corrected to read as follows:

Page 22	"iron-constantan" vice "iron-constanton."
Page 24	"a precision scale" vice "a precision scales."
Page 94	"trapezoidal" vice "trapizoidal."
Page 117	"mean streamline" vice "meanstream line."
Page 140	"static" vice "statis."

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TABLE OF SYMBOLS

Actual	Definition	FORTRAN	Units
A_1	Meridional cross-sectional area of rotor inlet	---	ft^2
A_5	Cross-sectional area of five-inch pipe	---	ft^2
BP	Probe to blade clearance, left and right	BPL, BPR	inches
C	Factor dependent on orifice diameter and type of pressure taps used	---	- - -
C_o	Velocity corresponding to the enthalpy drop through the turbine	---	ft/sec
C_f	Conversion factor	CF1	lb/ft^2/in Hg
CL	Axial Clearance	CL	inches
c_p	Specific heat (constant pressure)	CPS	$BTU/lb_m\,^oR$
$c_{p(av)}$	Average value of c_p based on t	CP	$BTU/lb_m\,^oR$
F	Scale reading	SR	lb
F_r	Reynolds number correction factor	---	- - -
G_{Hg}	Specific gravity of mercury at t_{rm}	GHG	- - -
G_{H20}	Specific gravity of water at t_{rm}	GWR	- - -
G_{oil}	Specific gravity of oil used in test cell manometers	GOL	- - -
g	Universal gravitational constant	32.174	lb_m-ft/lb-sec^2
HP_{is}	Power turbine could generate for an isentropic expansion	HPVC	HP

Actual	Definition	FORTRAN	Units
HP_s	Shaft horsepower	HP	HP
ΔH_w	Work output of turbine	DELH	Btu/lb_m
h_{atm}'	Measured atmospheric pressure reading (reference)	HATM	cm oil
h_{atm}	Measured atmospheric pressure reading (reference-SCROLL)	HATM	in H_2O
$h_{1(av)}$	Average measured pressure ahead of rotor	H1	in H_2O
h_{1A}	Measured total pressure reading at rotor discharge (used with h_{atm})	H1A	cm oil gage
h_{1B}	Measured total pressure reading at rotor discharge (used with h_2)	H1B	cm oil
h_2	Measured static pressure reading at rotor discharge	H2	cm oil
h_4, h_5	Measured pressure readings at rotor discharge for pitch angle	H4, H5	cm oil
h_{16}	Reading of reference static pressure, p_o, on mercury manometer board	H16	in Hg
h_{19}, h_{20}	Average reading of static pressures ahead of rotor on mercury manometer board for left and right side, respectively	H19, H20	in Hg
$\Delta h_{1vc}'$	Measured pressure across orifice (vena contracta taps)	DPVC	cm Hg
Δh_{1vc}	Actual pressure across orifice (vena contracta taps)	DVC	
J	Conversion factor	778.16	ft-lb/Btu

Actual	Definition	FORTRAN	Units
M	Moment exerted on dummy rotor	M	ft-lb
M_r	Ratio of measured dynamic pressure to measured absolute total pressure at discharge		
	- calibration curve values	CMR1, CMR2	- - -
	- measured value	CM	- - -
MV_2	Thermocouple readings for temperature survey at rotor discharge	VT2	mv
MV_4	Thermocouple reading ahead of orifice	V4	mv
MV_5	Thermocouple reading ahead of turbine	V5	mv
N	Measured turbine speed	RPM	rpm
P_{atm}	Atmospheric pressure (barometer)	PATM(SURVEY) BA(RADIAL)	in Hg
P_{to}	Absolute total pressure ahead of turbine	PTO	in Hg abs
P_{t2}	Actual total discharge pressure	PT2	in Hg abs
p_o	Absolute static pressure at turbine inlet	PS5	cm Hg abs
p_1	Average static pressure ahead of rotor inlet	P1	in Hg
p_2	Actual static discharge pressure	P2	in Hg abs
p_5'	Measure static pressure at turbine inlet	P5P	cm Hg gage
p_{1vc}'	Measured pressure upstream of orifice (vena contracta taps)	PUVC	cm Hg gage
p_{1vc}	Absolute pressure ahead of orifice (vena contracta taps)	PVC	cm Hg abs

Actual	Definition	FORTRAN	Units
R	Rotor discharge radius at which probe measurements are taken	R	inches
R_2	Actual discharge radius	R2	inches
R_g	Gas constant for air	53.35	$ft\text{-}lb/lb_m\,^oR$
r^*	Degree of reaction	DR	- - -
T	Torque developed by dynamometer	T	in-lb
T_{to}	Total temperature ahead of turbine	T5	^oR
T_{t2}	Total temperature at rotor discharge radii	TT2	^oR
T_E	Equivalent rotor inlet temperature	TE	^oR
T_{R1}	Relative total temperature at rotor inlet	TR1	^oR
T_{t4}	Total temperature ahead of orifice	T4	^oR
T_o	Static temperature at turbine inlet	TO	^oR
T_1	Static temperature at rotor inlet	T1	^oR
T_1'	Effective static temperature at rotor inlet due to losses guide vane exit and rotor inlet	T1P	^oR
T_2	Static temperature at rotor discharge radii	T2	^oR
T_2'	Static temperature at rotor discharge radii for isentropic expansion through rotor to p_2	T2P	^oR
ΔT_{is}	Isentropic temperature drop from P_{to}, T_{to} to P_{to}	DT	^oR

Actual	Definition	FORTRAN	Units
TQ	Torque indicator reading		
	- calibration data	TCD	- - -
	- measured values	TQ	- - -
t	Average temperature through the turbine	A	^oF
tare	Tare of mercury micromanometer	TARE	cm Hg
tare	Tare of precision scales	STARE	lb
t_{cj}	Cold junction temperature	TCJ	^oF
t_{rm}	Control room temperature	TRM	^oF
U_1	Peripheral speed of rotor at rotor inlet	U1	ft/sec
U_2	Peripheral speed at each radii, R, of the rotor discharge	U2	ft/sec
V_o	Velocity at turbine inlet	V1	ft/sec
V_1	Absolute flow velocity at rotor inlet	V1	ft/sec
V_{m1}	Meridional component of V_1	VM1	ft/sec
V_{u1}	Peripheral component of V_1	VU1	ft/sec
V_2	Absolute velocity at rotor discharge radii	V2	ft/sec
V_{m2}	Meridional component of V_2	VM2	ft/sec
V_{u2}	Peripheral component of V_2	VU2	ft/sec
V_{a2}	Axial component of V_2	VA2	ft/sec
W_1	Relative flow velocity at rotor inlet	W1	ft/sec

Actual	Definition	FORTRAN	Units
W_{u1}	Peripheral component of W_1	WU1	ft/sec
W_2	Relative flow velocity at rotor discharge radii	W2	ft/sec
W_{u2}	Meridional component of W_2	WU2	ft/sec
W_{2th}	Theoretical relative flow velocity at rotor discharge radii	W2TH	ft/sec
$\dot{W}_{vc}$	Mass flow rate (vena contracta taps)	WVC	lb_m/sec
X	Reynolds number factor		- - -
Y_1	Expansion factor accounting for thermal expansion of orifice		- - -
Z	Absolute viscosity		centipoises
α	Area multiplier accounting for thermal expansion of orifice	A	- - -
α_1	Absolute rotor inlet flow angle	ALP1	degrees
α_2	Measured yaw angle of flow at rotor discharge	ALF2	degrees
β_1	Relative rotor inlet flow angle	B1	degrees
β_2	Angle of relative discharge velocity	B2	degrees
γ	Ratio of specific heats	GAM	- - -
γ_{av}	Average value of based on t	GAM	- - -
δ	Referred pressure ratio	DEL	- - -
η_{is}	Local isentropic efficiency	ECC	- - -

Actual	Definition	FORTRAN	Units
η_L	Local efficiency from iteration for T_{t2}	EVCC	- - -
η_L	Local efficiency from measured T_{t2}	ETA	- - -
Φ_L	Carry-over coefficient	PHII	- - -
φ	Velocity coefficient of scroll and guide vanes	PHI	- - -
ψ	Velocity coefficient of relative velocities	PSI	- - -
ρ_o	Density at turbine inlet	RHO	lb_m/ft^3
ρ_2	Density at turbine discharge	RHO	lb_m/ft^3
θ	Pitch angle - calibration curve value - measured value	 THET THETA	 degrees degrees
ζ_R	Rotor loss coefficient	ZETA	- - -
P_{to}/p_1	Pressure ratio through the scroll and guide vanes	PR	- - -
P_{to}/p_2	Pressure ratio across turbine	PIN	- - -
p_1/p_2	Ratio of static pressures ahead of and after rotor	PIR	- - -
p_1/P_{to}	Ratio of rotor inlet static pressure to total pressure ahead of turbine	AP	- - -
$P_1'-P_{atm}$	Measured total pressure less atmospheric pressure at rotor discharge	DP1A	in H_2O
$P_1'-p_2'$	Measured dynamic pressure at rotor discharge	DP12	in H_2O

Actual	Definition	FORTRAN	Units
$P_1{}'-P_{t2}$	Difference between measured and actual total pressure at rotor discharge	DP1T2	in H_2O
$p_4{}'-p_5{}'$	Measured pressure difference between the two pitch angle pressure taps	DP45	in H_2O
$P_{t2}-p_2$	Actual dynamic pressure at rotor discharge	DPTS2	in H_2O
$\frac{p_1{}'-P_{t2}}{P_{t2}-p_2}$	Total pressure coefficient		
	- calibration curve value	TPC	- - -
	- measured value	TPCC	- - -
$\frac{p_4{}'-p_5{}'}{P_1{}'-p_2{}'}$	Pitch angle pressure		
	- calibration curve value	PPC	- - -
	- measured value	PPCC	- - -
$\frac{P_{t2}-p_2}{P_1{}'-p_2{}'}$	Velocity pressure coefficient		
	- calibration curve value	VPC1, VPC2, and VPCX	- - -
	- measured value	VPCC	- - -
$\frac{h_{19}+h_{20}}{2}$	Average of h_{19} and h_{20}	P1	in Hg
$(1-r^*)\Delta T_{is}$	Isentropic temperature drop through scroll and guide vanes	B	^oR
$\frac{\gamma-1}{\gamma}$	Exponent using γ_{av}	EXP	- - -
$2gJc_p$	Convenient factor	G	$ft^2/sec^2/^oR$

Actual	Definition	FORTRAN	Units
	Mass flow averaged values for left and right rotor discharges		
$T_{t2(av)}$	- total discharge temperature	TAL, TAR	^oR
$\dot{W}_{av}$	- mass flow	WL, WR	lb_m/sec
$W_{2(av)}$	- relative flow velocity	WAL, WAR	ft/sec
$W_{2th(av)}$	- theoretical relative flow velocity	WATL, WATR	ft/sec
η	- overall efficiency based on HP_s and HP_{is}	EVCL, EVCR P?	- - -
η	- overall efficiency based on T_{t2}	ETAL, ETAR	- - -
Ψ_{av}	- velocity coefficient	PAL, PAR	- - -
ζ_R	- rotor loss coefficient	ZAL, ZAR	- - -

1. Introduction.

The radial turbine held a relatively minor position in the field of turbomachinery prior to the last two decades. With the advent of the space age radial turbines were utilized more, especially as small gas turbines for auxiliary equipment and as expanders for aircraft environmental systems and for cryogenic purposes. The present tendency toward smaller and smaller turbomachinery has given radial turbines greater utility since they can operate at efficiencies higher than those of axial turbines with small blade heights. Consequently, performance parameters must be established to aid in the design of these turbines. The parameters obtained through testing with air at nearly atmospheric pressures can be applied to geometrically similar turbines that will operate with different fluids at pressures of a far different order of magnitude. The objective of this report is to establish some of these parameters for a particular radial turbine, including the effects of axial clearance.

Because the evaluation of the performance parameters is an analytical problem of considerable magnitude, it is desirable to program the analysis for use on a computer. Three such programs are used in this report. Program SURVEY was written to determine the performance parameters for several different discharge radii, using data obtained from the pressure survey of the rotor discharges.

Program RADIAL, written by Vavra [9][1] and modified for the present test installation, computes the referred performance parameters using a mean streamline analysis. The third program, SCROLL, was written to evaluate conditions at the rotor inlet for use in programs SURVEY and RADIAL.

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mean (time-averaged) flow, assumed to be streamlined.

The author wishes to acknowledge the guidance and encouragement given by Dr. M. H. Vavra of the Department of Aeronautics. Also special thanks go to J. E. Hammer and the other technicians within the department.

2. Installation and Instrumentation.

The turbine used in this investigation is a dual discharge, radial in-flow turbine installed at the Propulsion Laboratory of the Department of Aeronautics at the Naval Postgraduate School. The turbine installation and instrumentation are shown in Figs. 1 and 2, respectively.

The turbine rotor (Fig. 3) is 9.40 inches in diameter with an axial length of 5.00 inches. The rotor discharge radius is 1.76 inches at the hub and 2.94 inches at the tip. The 15 blades have a spacing at the discharge varying from 0.737 to 1.232 inches, hub to tip, respectively. The actual rotor discharge area on one side of the rotor is 6.4325 inches.

The wooden inlet casing has an inner contour, formed by plaster of Paris, in the shape of a varying diameter torus or scroll. The shape of the scroll was obtained by

[1]Figures in brackets refer to bibliography entries of section 8.

casting the plaster around a wooden insert of the desired scroll dimensions. The inner surface of the scroll has been varnished to prevent erosion. A cross-section of the casing showing the shape of the scroll and the location of the seven guide vanes can be seen in Fig. 4. Shown in Fig. 5 is the cross-section of the turbine, indicating the turbine dimensions and the clearances that existed after the final alignment check.

Alignment of the scroll with respect to the rotor was accomplished by the use of the dummy shaft and micrometer dial gages shown in Fig. 6. The scroll was positioned by four adjustment screws located at the bottom of the inlet casing and by four angle irons attached to the casing and resting on the bearing supports. Final measurements with the dummy shaft and dial gages indicated that the aluminum rings that hold the shrouds in place were concentric with respect to the rotor axis within $\pm$ 0.001 inches, and that the rings deviate from a plane perpendicular to the rotor axis by less than 0.003 inches at a radius of 4.7 inches.

The original metal shrouds were replaced with plexiglass shrouds whose contours more nearly match those of the rotor blading. The right shroud can be seen in Fig. 7. Plexiglass was used to permit flow visualization when running the turbine in conjunction with a smoke generator. The axial clearance between the rotor and the shrouds was increased by use of circular metal shims inserted between the shrouds and the aluminum rings that hold the shrouds in place.

The source of air for the operation of the turbine was an Allis-Chalmers 12-stage axial compressor. Air from the main supply line passes through a four-inch pipe, a settling tank, a five-inch pipe, and then into the turbine. The flow rate was regulated by the two remotely controlled butterfly valves shown in Fig. 8. The controls and reference gages for operating the valves were located in the control room (Fig. 9).

The flow rate through the turbine was measured with a sharp edged orifice located in the four-inch pipe (Fig. 8). The pressure ahead of the orifice and the pressure difference across the orifice were measured with so-called standard flange and vena contracta taps. The temperature ahead of the orifice was measured with a chromel-alumel thermocouple installed in a Kiel temperature probe. The total pressure measured by the Kiel probe was not used for the data reduction. The installation conforms to standards set forth by Stearns, et. al. [7]. 8

The torque developed by the turbine was absorbed by an air dynamometer manufactured by Vortec Products Company. The dynamometer was equipped with a torque capsule capable of absorbing up to 400 in-lb. The torque was measured with strain gages that are arranged in the capsule. The signal of these strain gages were read in the control room with a Daytonic Strain Gage Digital Indicator (Fig. 9). Speed regulation of the turbine could be effected by a remote controlled device that changes the load capacity of the

dynamometer. The dynamometer was connected to the turbine by means of a steel quill shaft (Fig. 10). To prevent the dynamometer discharge from interfering with the right rotor discharge, a wooden baffle was mounted between the dynamometer and the turbine (not shown in Fig. 1).

The turbine speed was obtained from readings of a Hewlett Packard electronic counter (Fig. 11) that is located in the control room. The signal for the counter is obtained from a magnetic pickup used in conjunction with a six lobe flux cutter arranged on the quill shaft.

The two pressure probes, United Sensor Model DA-120, used to survey the rotor discharge are shown with their associated differential manometer boards in Fig. 1. The probes are three-dimensional, measuring the yaw and pitch angles and the total and static pressures. The probes were mounted in holders located on top of the inlet casing with the probes passing through the upper portion of the casing and the shrouds. The probes can be moved vertically and turned about the vertical axis. Fig. 5 shows the location of the probes in the discharge plane. A sketch of a probe head can be seen in Fig. 12. The manometer boards were located in the test cell since the probes were adjusted by hand to establish the radial position and correct yaw angle. Because the probe holes were small, manometer fluid (oil) with a specific gravity of 0.834 and thin glass manometer tubes were used to reduce the response time. The manometer could be read accurately within 0.1 cm. Fig. 13

shows the hook-up between the manometer board and the probes. Calibration curves for both probes, provided by the manufacturer, were checked and found reliable.

The two temperature probes used for the discharge surveys were locally manufactured. They are stagnation type probes utilizing iron-constantan thermocouples. The probes were mounted in holders similar to those used for the pressure probes. Because of space limitations and assuming constant discharge conditions in the peripheral direction, the holders (not shown in Fig. 1) were located on the outside of the casing opposite the turbine inlet. The distance of the probes from the trailing edges of the rotor blades was the same as that for the pressure probes. A sketch of a probe head can be seen in Fig. 12.

A second Kiel temperature probe was located in the five-inch pipe just upstream of the turbine inlet. The total temperature at this station was also measured with a chromel-alumel thermocouple. The total pressure, read on a Heise gage (Fig. 14) in the control room, was used for setting the desired turbine pressure ratio (total inlet to static discharge). Located at the same position in the five-inch pipe were two pressure taps used to obtain the static pressure at the turbine inlet. The static pressure ahead of the rotor was measured with pressure taps located in the shrouds. The location of the taps, eight per shroud, is shown in Fig. 4. The taps from each shroud were connected to a manifold to obtain an average pressure reading for each side.

The static pressure at the turbine inlet and the pressures obtained from the flange and vena contracta taps were measured on a 100-cm. mercury micromamometer with a measuring accuracy of ± 0.01 cm. The average static pressures ahead of the rotor were measured on a 40-inch mercury manometer board with a measuring accuracy of ± 0.02 inches. The manometer board was used as a differential manometer with the static pressure at the turbine inlet connected to the manometer reservoir as reference pressure. The manometers were located in the control room.

A 48 channel Brown Potentiometer, manufactured by Minneapolis Honeywell, was used to measure the voltage potential generated by the thermocouples. The potentiometer (Fig. 14) was located in the control room and uses an ice bath in the test cell as a cold junction reference.

Lubrication for the turbine bearings was provided by the unit shown in Fig. 15. Oil fumes were discharged outside the test cell through a flexible vent line. Lubrication of the dynamometer was accomplished by an oil mist generated by air pressure. The bearing oil pressure and the dynamometer air pressure were measured on gages located in the control room. The turbine bearing vibration signals generated by a piezo-quartz accelerometer mounted on the upper left bearing block were displayed on a Panoramic Vibration Analyzer of the Singer Metrics Company (Fig. 11).

A special installation, shown in Fig. 16, was used to evaluate the losses in the scroll and guide vanes as well

as the absolute flow angle at the rotor inlet. The test rotor was replaced by a dummy rotor (Fig. 17) with 36 meridional blades which turn the flow leaving the guide vanes into the axial direction at the rotor discharge. The diameter of the dummy rotor was 8.75 inches since the rotor was built for an earlier test where additional clearance was required between the rotor inlet and the guide vanes for insertion of a Pitot probe. Since the static pressure taps ahead of the rotor are located at a diameter of 9.50 inches, the outer diameter of the existing dummy rotor was increased to this value by welding special metal strips to the rotor blades. The blade contours were then reworked to coincide as closely as possible with the shroud contours. The axial length of the rotor is 8.50 inches. The dummy rotor was mounted on two self-aligning ball bearings attached to the special stand that supports the inlet casing. Centering of the rotor was accomplished by the use of shims and micrometer gages. Final measurements indicated a maximum axial clearance of 0.0165 inches and a radial clearance at the discharge of 0.035 inches. Attached to the rotor shaft was a 12-inch moment arm at whose end the moment exerted by the flow on the stationary dummy rotor was measured by means of a precision scales.

For the dummy rotor tests, the 16 pressure taps used to measure the static pressure ahead of the rotor inlet were individually connected to a 96-inch water manometer board with a measuring accuracy of ± 0.05 inches. The static pressures were measured against atmospheric pressure.

3. Description of Test Runs

A total of five runs were carried out at axial tip clearances of 0.027, 0.042, 0.047, 0.052 and 0.057 inches, the clearance being measured at one side of the rotor inlet. Each run was made at three total inlet to static discharge pressure ratios of 1.30, 1.55 and 1.70. To determine the effects of axial clearance on the turbine performance, particularly overall efficiency, the turbine was operated at three speeds for each pressure ratio. One speed was selected to obtain as nearly as possible the optimum efficiency as determined by Finn [3]. The two other speeds were chosen to obtain useful curves illustrating clearance and pressure ratio effects. The three speeds for each pressure ratio were held as constant as possible for the runs to give the best correlation of data. The recorded data is listed in Tables D1 and D2.

The dynamometer was calibrated before each run by applying weights to a lever arm. While the load was increased and decreased, the strain gage indicator was adjusted at the no load and full load conditions until consistency existed between two successive loading cycles. The calibration data is tabulated in Table A2.

The general procedures used in conducting each run were as follows:

1. The dynamometer load was increased to its maximum to obtain the minimum turbine speed.

2. Supply pressure was increased until the value of the desired pressure ratio was obtained (starting with the minimum pressure ratio).

3. The dynamometer load was reduced until the desired value of the turbine speed was obtained.

4. When the total turbine inlet temperature had stabilized, the data was recorded.

5. Steps 3 and 4 were repeated for the two other speeds.

6. Steps 1 through 5 were repeated for the two other pressure ratios.

Because of the slight hysteresis in the torque calibration curve data, and since experience showed that the pressure ratio and the speed each affected the other, the speed was increased in small intervals as the desired speed setting was approached. The pressure (indicated on the Heise gage) was allowed to stabilize between intervals. This prevented overshooting the desired speed permitting the use of the decreasing load torque calibration curve data in the torque calculations.

During the first run, several faulty components were discovered. The Kiel probe at the turbine inlet leaked. Therefore, the pressure ratio settings were in error. Leaks in the valving set-up used with the mercury micromanometer resulted in incorrect readings for the orifice pressures and for the static inlet pressure. During the discharge pressure survey, the left probe apparently had slipped in the holder since the yaw angle readings were inconsistent with the probe head position. These discrepancies were rectified and the run repeated. Discharge pressure surveys were made at speeds of 10,162, 17,869, and 18,952 rpm for pressure ratios of 1.30, 1.55, and 1.70, respectively.

Prior to the second run, five 18 squares per inch wire mesh screens were inserted in the five-inch pipe approximately seven feet upstream of the turbine inlet. This was done in an attempt to dampen slight pressure fluctuations which were noticed during the first run.

Runs 2 and 3 were carried out without major problems. The wire screens had the desired effect since they reduced the pressure fluctuations almost entirely. Discharge pressure surveys were made for all of the test points of both runs. In the second run at a pressure ratio of 1.7 a high frequency sound was heard as the turbine speed approached 18,000 rpm. Since there was no change in the vibration pattern on the Vibration analyzer, or any indication of problems in the test cell, the data was recorded and the turbine shut down. A visual check of the turbine and dynamometer gave no evidence of rubbing. It was concluded that the noise was produced by a resonant condition of the air flow through the dynamometer. In run 3 this condition was verified. As the speed was carefully increased, the noise level diminished above about 18,500 rpm.

Originally it was planned to carry out only three runs, but the results of the data reduction showed a relatively large decrease in efficiency between runs 2 and 3. Therefore, two additional runs were made to obtain a better definition of the clearance at which the efficiency starts to drop off radically. Discharge surveys were made for the fifth run only, and included temperature surveys, the probes

having been installed just prior to the run. The surveys were made at speeds of 10,144, 11,824 and 16,050 rpm for pressure ratios of 1.30, 1.55 and 1.70, respectively. During run 5, an additional test point was taken at a pressure ratio of 1.55 to check the previously made choice of the speed for the optimum turbine efficiency.

At the higher speeds during several runs, it was noticed that the equalization of the two static pressures measured by the survey probes were somewhat insensitive within a range of yaw angle of about 10 degrees. Hence, the correct yaw angle setting was chosen at the center of this range.

After completion of the five runs, the turbine was dismantled and the special installation for measuring the scroll and guide vane losses and the absolute rotor inlet flow angle was set up. Before obtaining these data, the quantities determined by Vavra [10] were used for the evaluation of the test data.

The dummy rotor was originally fitted with extensions at every other blade, but flow visualization with tufts at the rotor discharge showed back-flow patterns in the passages downstream of the extensions. Therefore, extensions were added to all blades. After this rework, the discharge flow was found to be relatively steady and without whirl components or back-flow.

Because of the large number of water manometer tubes and the pressure fluctuations noticed during the test,

Polaroid pictures were taken of the manometer board for more accurate data recording. The pressures were then read from the photographs with a magnifying glass. Recorded data for this test is listed in Table D3.

4. Data Reduction.

The reduction of data was carried out with three computer programs, RADIAL, SURVEY and SCROLL. The programs were processed on the Control Data Corporation 1604 Computer of the Naval Postgraduate School.

Program RADIAL performs a mean-streamline analysis of the turbine. A detailed description of the program is given by Vavra [10]. The program was modified to accommodate the installation and instrumentation used for these tests. The changes are explained in Appendix B.

Program SURVEY reduces the data obtained from the rotor discharge pressure and temperature surveys, but can be used without the temperature data as it was done for the majority of the runs. The program utilizes a one-dimensional approach for the data reduction.

Program SCROLL establishes the scroll and guide vane losses and the absolute rotor inlet flow angle which are then used in programs RADIAL and SURVEY.

Detailed descriptions of SURVEY and SCROLL are given in Appendices A and C. A brief description of the analysis used in the latter two programs is given in this section.

Program SURVEY

The value of the specific gravity of mercury at room temperature is given by Eq. (A2). All measured pressures are then reduced to mercury with an average specific gravity of 13.59.

The turbine flow rate is obtained from Eq. (A9) determined by Vavra.[1] Only vena contracta tap data is used in the flow rate equation since it is slightly more accurate than the flange tap data.[2]

The pressure survey data is reduced using the calibration curves (Figs. A2 and A3). From the curves, the pitch angle Θ, the actual dynamic pressure ($P_{t2} - p_2$), and the total discharge pressure are obtained. To obtain the actual dynamic pressure, the Mach number error factor M_r must first be determined by Eq. (A4).

The total inlet pressure P_{to} based on the average velocity V_o, is used in the data reduction. This pressure is more representative of the actual conditions at the turbine inlet than is the total pressure measured at the center of the five-inch pipe with the Kiel probe. V_o can be determined by iteration using the gas law, the continuity equation and the energy equation (Eqs. (A21) through (A23)). P_{to} is then obtained by Eq. (A24).

[1]Vavra, M. H. Results of Turbine Air Testing Program, Phase II, Report ALGR No. 29, for Aerojet General Corporation (1965), p. 219.

[2]*Ibid.*, p. 220.

The thermodynamic process of a fluid passing through the turbine can be seen in the Entropy diagram of Fig. 18. The velocity diagram for the turbine is shown in Fig. 19. Using these diagrams, a majority of the relations for the turbine parameters were obtained. The degree of reaction r* is determined by Eq. (A35). With the values of the velocity coefficient φ defined by Eq. (A36) and the absolute rotor inlet flow angle α_1 (both determined by program SCROLL), the parameters at the rotor inlet can be obtained using Eqs. (A37) through (A43).

To account for non-uniform flow conditions at the rotor inlet and for possible flow separation at the rotor blades due to the incidence angle of the flow approaching the rotor, the carry-over coefficient Φ_i is introduced. It was assumed that the useful kinetic energy at the rotor inlet is $\Phi_i W_1{}^2/2gJc_p$ and that $\Phi_i = V_{m1}{}^2/W_1{}^2$ [11]. Hence, the effective static temperature at the rotor inlet is given by Eq. (A46) and the temperature at state point 2' follows by Eq. (A47).

To determine the theoretical relative velocity W_{2th} at the rotor discharge, the temperature at state point E given by Eq. (A44) is required. The equivalent state point E represents the total condition that would exist at the rotor inlet if the rotor were considered as a stationary passage with static discharge pressure p_2. With T_E and T_2', W_{2th} can be obtained from Eq. (A48).

If the total discharge temperature T_{t2} has not been measured, it must be determined by iteration. The first approximation of T_{t2} is given by Eq. (A49) which assumes that the efficiency η_{is}, obtained from Eq. (A32), is constant in the radial direction. The second approximation of T_{t2} follows from Eqs. (A53) through (A56) using T_{t2} from the first approximation. By increasing or decreasing η_{is} in Eq. (A49) until the two values of T_{t2} agree within 0.05°, the local efficiency η_L and the discharge velocity V_2 in addition to T_{t2} are determined.

The relative discharge velocity W_2 and flow angle β_2 are obtained from Eqs. (A57) and (A60), respectively. The rotor loss coefficient which is a measure of the kinetic energy loss through the rotor is given by Eq. (A61) where the velocity coefficient ψ is defined by Eq. (A62).

If T_{t2} has been measured, the discharge parameters can be determined without the discharge iteration. The local efficiency can be obtained from Eq. (A67). The local value of the velocity coefficient φ and the rotor inlet parameters are determined by iteration. The first approximation of the relative rotor inlet velocity W_1 is obtained using Eq. (A37) where φ is initially set equal to unity and Eqs. (A64) through (A66). The second approximation of W_1 follows from Eqs. (A39) through (A43) using V_1 as determined by Eq. (A37) in the first approximation. The iteration continues by reducing φ in steps of 0.0001 until the two approximations of W_1 agree within 1.0 ft/sec. The iteration

uses the value of α_1 determined by program SCROLL. The theoretical relative discharge velocity W_{2th} is obtained from Eqs. (A46) through (A48).

Program SCROLL

The value of the specific gravity of water at room temperature is given by Eq. (C1). As in SURVEY, the measured pressures are reduced to mercury with an average specific gravity of 13.59. The equations used for determining the turbine flow rate and in iterating for the total turbine inlet pressure are the same as those used in SURVEY.

From the theorem of angular momentum[1] for a steady flow that does not have a whirl component at the rotor discharge ($V_{u2} = 0$), the moment M exerted on the dummy rotor of radius 4.75 inches is given by Eq. (C3). The peripheral component of the absolute rotor inlet velocity V_1 is given by Eq. (C4), with the moment expressed by the product of the scale reading F and the length of the moment arm (12 inches).

The velocity coefficient φ is determined by an iteration using V_1 as given by Eq. (A37). The first approximation of V_1 is obtained by setting φ equal to unity. The second approximation of V_1 follows from Eqs. (C5) through (C9) using V_1 determined for the first approximation. The actual value of φ is obtained by reducing φ by increments of 0.0001 until the two approximations for V_1 agree

[1] Vavra, M. H. Aero-Thermodynamics and Flow in Turbomachines (John Wiley and Sons, 1960), p. 98.

within 1.0 ft/sec. The absolute rotor inlet flow angle α_1 is then given by Eq. (C10).

5. Discussion of Results

The results of program RADIAL are listed in Tables E1 through E9. Tables E1, E2 and E3 give data of the overall performance values, Tables E4, E5 and E6 show the resulting blading parameters and Tables E7, E8 and E9 give the loss coefficients of the blading. The tables within each group are for zero, minimum and maximum bearing losses, respectively. The significant results are plotted in Figs. 20 through 28.

The results of program SURVEY are listed in Tables E10 and E11. Table E10 gives the data based on the iterated discharge temperature whereas Table E11 gives the data based on the measured discharge temperature. The significant results of the pressure surveys made at a pressure ratio of 1.70 and at the speed for the optimum efficiency for runs 2 and 3 are shown in Figs. 29 through 32.

The results of program SCROLL are listed in Table E12. The value of the velocity coefficient φ was found to be independent of the pressure ratio P_{to}/p_1. Therefore, an average value of the results, 0.889, was used in programs SURVEY and RADIAL. Even though the flow angle α_1 decreased with an increase in P_{to}/p_1, a representative value of 80.0 degrees based on the range of P_{to}/p_1 for program SURVEY was used.

In Tables E1, E2 and E3, it can be seen that the difference between the efficiencies for maximum and minimum bearing losses is less than two points, whereas the difference between the efficiencies for minimum and no bearing losses ranges from about eight points at a pressure ratio of 1.30 to about three points at a pressure ratio of 1.70. From this it was concluded that the minimum bearing losses would be fairly representative of the actual bearing losses. Therefore, using the results from Table E2, the blading efficiencies were plotted as a function of the velocity ratio U_1/C_o in Figs. 20 through 24 for clearances of 0.027, 0.042, 0.047, 0.052 and 0.057 inches, respectively. The maximum efficiency is 85.5% obtained at a clearance of 0.027 inches (run 1) and a pressure ratio of 1.70. Since only three points were investigated at each pressure ratio for each run, the general shape of each curve was obtained from similar curves determined by Vavra [10]. Using a comparison based upon equivalent clearances, the efficiencies shown in Fig. 23 are slightly more than one per cent lower than the efficiencies found by Vavra.[1] Moreover, the merging of the curves for pressure ratios of 1.55 and 1.70 in the area of maximum efficiency is not in evidence. These variations may be attributed to the difference in the shape of the new plexiglass shrouds used in this test and the old shrouds used by Vavra. It was also noticed that the efficiencies

[1]Vavra, M. H. Results of Turbine Air Testing Program, Phase II, Report ALGR No. 29, for Aerojet General Corporation (1965), p. 161.

in Fig. 20 are approximately seven per cent lower than the efficiencies determined by Finn.[2] This difference must be due to the difficulties Finn had with the torque capsule.[3]

The merging mentioned above is definitely part of a trend that can be seen in Fig. 25 where maximum efficiency is plotted as a function of the axial clearance with the pressure ratio as parameter. As the clearance increases, the two curves converge, merging at a clearance ratio CL/CL_{min} of 1.92 (CL_{min} = 0.027 inches), and then diverge from the curve for a pressure ratio of 1.55 having the higher efficiency. This is true except for one point as shown in Fig. 24. Further testing would be necessary to determine whether or not this point is in error. The point may be reliable since an increase in clearance appears to have a greater influence on the efficiencies near or below the speed for maximum efficiency.

As depicted in Fig. 25, the efficiencies remain relatively constant until the critical clearance ratio of 1.92 is reached. As the clearance ratio increases beyond this point, the efficiency drops off radically. This phenomenon is explained in part by Csanady.[4] As the rotor blades move over the stationary shrouds, the leading surfaces of the

[2]Finn, W. A. "Performance Investigation of a Dual Discharge Radial Inflow Turbine" (unpublished Master's thesis, Naval Postgraduate School, 1966), p. 97.

[3]*Ibid*., p. 40.

[4]Csanady, G. T. *Theory of Turbomachines* (McGraw-Hill, 1964), pp. 289-90.

the blades "scrape up" the boundary layer that exists on the shrouds and produces a vortex in the tip region. In a turbine this vortex is opposed to the tip vortex. This "scraped up" vortex tends to nullify the tip vortex, and at a particular tip clearance the two effects neutralize each other, leaving only the passage vortex which causes the so-called secondary flow losses. For the pressure ratios investigated, the neutralization point appears to be at an axial clearance less than 0.027 inches. The tip vortices become more predominant as the clearance increases, but there is also some build-up of the boundary layer which tends to maintain a reasonably even balance between the two vortices. The rate of increase of the tip vortices over the "scraped up" vortices appears to increase slightly with an increase in the pressure ratio as might be expected. As the critical clearance is passed, the effectiveness of the boundary layer as a vortex-producing medium decreases radically whereas the losses associated with the tip vortex continue to increase. These same phenomenon were observed by Epifanova from the results of tests on a radial in-flow, single discharge, adjustable expansion turbine.[5]

Fig. 26 shows the referred turbine flow rate as a function of the turbine pressure ratio. Only the data for the vena contracta taps are presented. The lines of constant velocity ratio U_1/C_o were established by auxiliary curves

[5]Epifanova, V. I. Radial Flow Low Temperature Expansion Turbines (Vol. 4 of Progress in Cryogenics, ed. K. Mendelssohn. 4 Vols.; Academic Press Inc.; 1964), p, 9.

of referred flow rate plotted as a function of U_1/C_o. Using three curves, one for each of the pressure ratios investigated, the curves were cross-plotted in Fig. 26. At a fixed pressure ratio, the flow rate decreases with increasing values of U_1/C_o.

From the data for the minimum bearing losses, the referred turbine moment was plotted as a function of referred speed in Fig. 27 with the total-to-static pressure ratio as parameter. For a given pressure ratio, the clearance had negligible effect on the curves until the critical clearance ratio was reached. For clearance ratios larger than the critical one, the moment decreases somewhat.

The degree of reaction as a function of the velocity ratio is shown in Fig. 28. Only the results of program RADIAL are depicted, but the data from program SURVEY are in agreement with the curve. Contrary to what was expected, the degree of reaction is independent of the axial clearance and turbine pressure ratio for any given velocity ratio. The degree of reaction could be higher, but an area mismatch exists between the guide vanes and rotor discharge areas.[6] A detailed explanation and the proposed modifications are given in [10]. A similar curve obtained from the results of tests made on a radial in-flow, single discharge, shrouded rotor turbine is also shown in Fig. 28.[7] The curves are vertically displaced from one another, but the

[6]Vavra, op. cit., p. 61.

[7]Epifanova, op. cit., p. 5.

trend in their slopes is similar. It appears that neither the axial clearance nor the turbine pressure ratio were varied during these tests.

Using the results of program SURVEY, the loss coefficient and the static temperature and pressure distributions were plotted in Figs. 29 and 30 for runs 2 and 3, respectively. As can be seen in both figures, the losses and the static temperature increase from hub to tip, with the losses becoming relatively constant over the outer half of the rotor discharge. The rise in both cases is due, in part, to the influence of the tip losses and the shroud boundary layer losses. The temperature rise is due to the conversion of energy losses into heat. The slight rise in both the losses and the temperature at the hub is due to the additional boundary layer growth between the blades. A detailed discussion of the losses is given by Csanady[8] and Vavra.[9] A comparison of Fig. 29 with similar values for run 5 in Table E10, for the same pressure ratio and speed, indicates that the clearance has negligible effect on the above parameters as long as the efficiency remains relatively constant. As expected, the loss coefficients increased and the temperature drop from total inlet to static discharge decreased with decrease in efficiency. The static pressures compared closely for both runs considered, remaining relatively constant

[8] Csanady, _op_. _cit_., pp. 267-96.

[9] Vavra, M. H. _Aero-Thermodynamics and Flow in Turbomachines_ (John Wiley and Sons, 1960), pp. 374-83.

and below atmospheric pressure, except at the tip where the pressure approaches atmospheric.

The meridional velocity and the flow angle distributions at the rotor discharge are shown in Figs. 31 and 32, for runs 2 and 3, respectively. The rapid increase of V_{m2} near the blade tip is due, in part, to the influence of the higher energy flow between the blade tip and the shroud. This leakage flow that passes through the clearance gap, without contributing to the work done by the rotor, is a cross flow that is not parallel to the streamlines that exist in the blade passages, as shown by Csanady[10] and Vavra.[11] This flow has a relatively large meridional component compared to the peripheral component. As might be expected, this effect does not appear to be influenced by the axial clearance at the rotor inlet.

The magnitude and distribution of the flow angles compares closely between the two runs, except for the magnitude of the absolute flow angle α_2 which increases about eight degrees on the average for run 3. Since the magnitudes of V_{m2} and β_2 are relatively equal for the two runs, apparently the losses should also be about equal. Yet there is an increase in the losses in run 3. Therefore, W_{2th} must increase from run 2 to run 3. The increase in W_{2th} is probably due to the decrease in rotor speed from 15,880 in run 2 to 15,420 rpm in run 3. It is possible that other factors,

[10]Csanady, _op. cit._, pp. 282-285.

[11]Vavra, _op. cit._, pp. 280-83.

such as pitch angle and pressure ratio differences, account for some of the reduction in W_{2th}. The pitch angle does have an appreciable effect at the rotor hub and near the rotor blade tips. Also shown in Figs. 31 and 32 is the distribution of the actual blading discharge angle β_{2th} derived from blading geometry.[12] As can be seen, the curves for β_2 and β_{2th} compare closely for both runs except in the area of the rotor tip.

The difference between the parameters for the left and right discharges in Figs. 29 through 32 could be due to the difference in blade-to-probe clearance for the two probes. Since a baffle was installed between the dynamometer and the right rotor discharge, there can be very little interference attributed to the dynamometer discharge air.

In reviewing the results of program SURVEY, a comparison was made of the mass flow rates determined by the metering orifice and the iteration of the conditions at the rotor discharge. Only 7 of the 24 surveys exceeded a difference of five percent, which was considered a reasonable tolerance for measuring error and for use of the trapezoidal rule for integration. Also, only in these seven cases was the mass average of the loss coefficient ζ_R less than zero or lower than expected. A majority of these discrepancies occurred at high turbine speed. As previously mentioned in section 3, there was some insensitivity in setting the yaw angle α_2

[12] Vavra, M. H. Results of Turbine Air Testing Program, Phase II, Report ALGR No. 29, for Aerojet General Corporation, (1965), p. 172.

in this area. Since the mass flow rate determined from the rotor discharge conditions and δ_R are a function of α_2, this may account for the discrepancies.

For a number of the surveys, some of the velocity coefficients Ψ of the rotor are greater than unity at the smaller discharge radii. This indicates that W_2 is greater than W_{2th}. From the one-dimensional approach, the contribution of the rotational velocity U_2 in the determination of W_{2th} decreases with decreasing discharge radii. Since W_{2th} is also dependent on the rotor inlet conditions, particularly on the carry-over coefficient Φ_1, a more sophisticated three-dimensional analysis is required to determine W_{2th} more accurately. This should result in greater values of theoretical relative velocity at the hub with possible reduction of the values near the tip.

6. Conclusions and Recommendations.

At a pressure ratio of 1.70 and a clearance of 0.027 inches, a maximum total-to-static efficiency of 85.5% was obtained for the case of minimum bearing losses. For the same conditions at a clearance of 0.052 inches, the efficiency was 84.1%. This indicates that a maximum clearance of 0.052 inches is permissible for a reduction in efficiency of less than two per cent compared with the optimum value at the minimum clearance. This larger clearance tolerance is very important in small turbines where the ratio of the minimum clearance to the rotor diameter is considerably greater than the same ratio for larger turbines. Also for

gas turbines where thermal expansion is a problem, it is felt that this additional clearance will be beneficial. To obtain a more accurate representation of the actual efficiency, new run-down bearing tests should be made to determine the effects of bearing temperature on bearing losses. The possible use of smaller diameter bearings with lower losses should be explored also.

The enlarging of the guide vane discharge area or the reduction of rotor discharge area to improve matching would increase the pressure ahead of the rotor. This would decrease the absolute rotor inlet velocity, increase the degree of reaction, reduce the rotor inlet incidence losses, and increase the relative discharge velocity W_2. The increase in W_2 would reduce the positive peripheral velocity V_{u2} which would give greater turbine work, thus higher efficiencies. Increasing the guide vane discharge area would probably be the easiest since the vanes are held in place with pins. By setting the existing blades at a smaller discharge angle, the discharge area would be increased, and the losses due to incidence angle would be decreased.

Increasing the actual rotor blading discharge angle β_{2th} near the blade tip would also reduce V_{u2} and increase W_2. This may not be structurally possible due to stress limitations or economically feasible due to machining costs.

The data presented in this report should give valuable information for off-design operations of geometrically similar turbines. More testing is recommended in the area of

maximum clearance to obtain a more accurate picture of the performance parameters, particularly for off-design conditions. The possibility of a correlation between the degree of reactions for different types of radial turbines needs to be investigated to give more flexibility in turbine design.

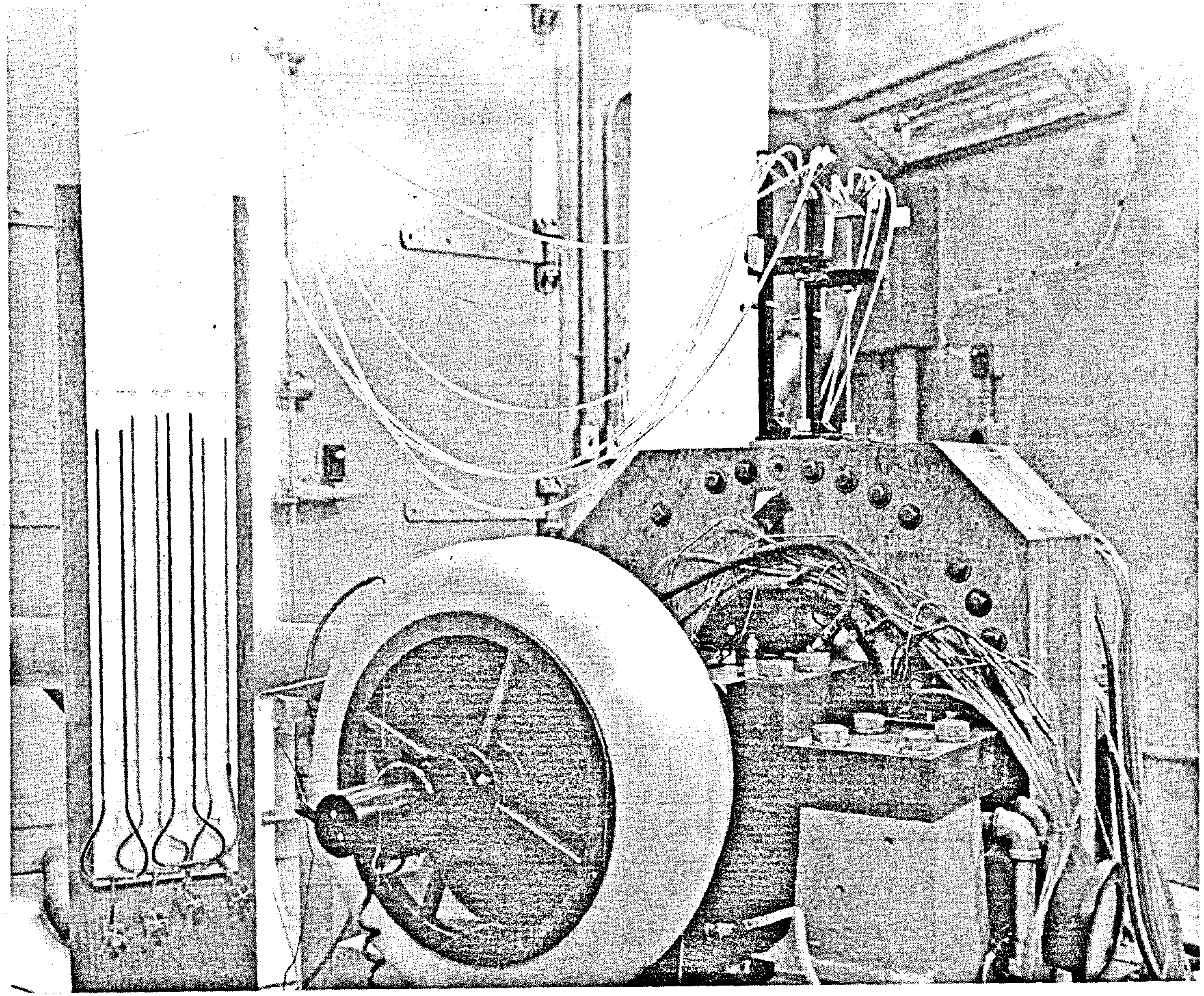


Fig. 1 Turbine Installation

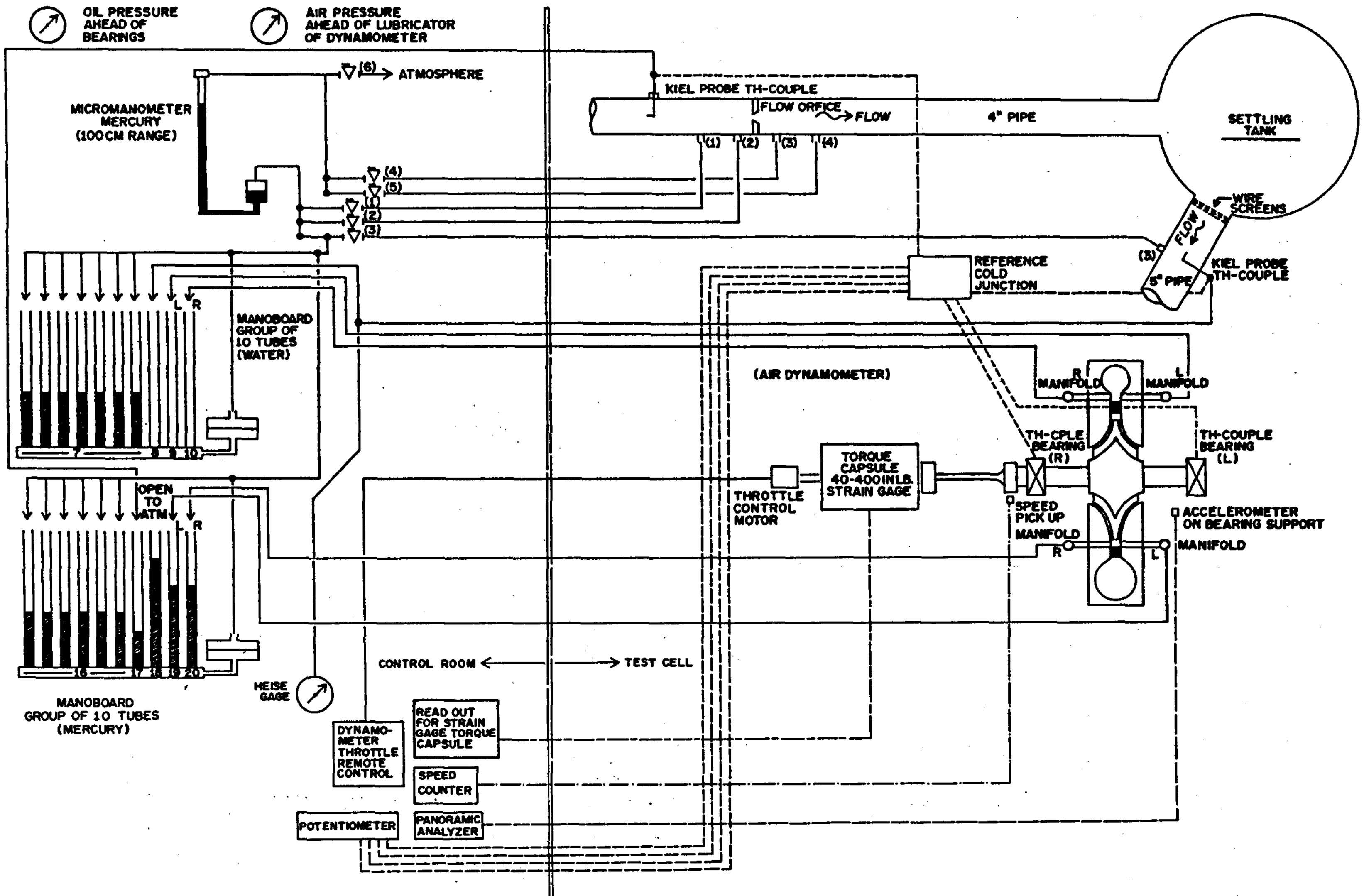


Fig. 2

RADIAL TURBINE INSTRUMENTATION

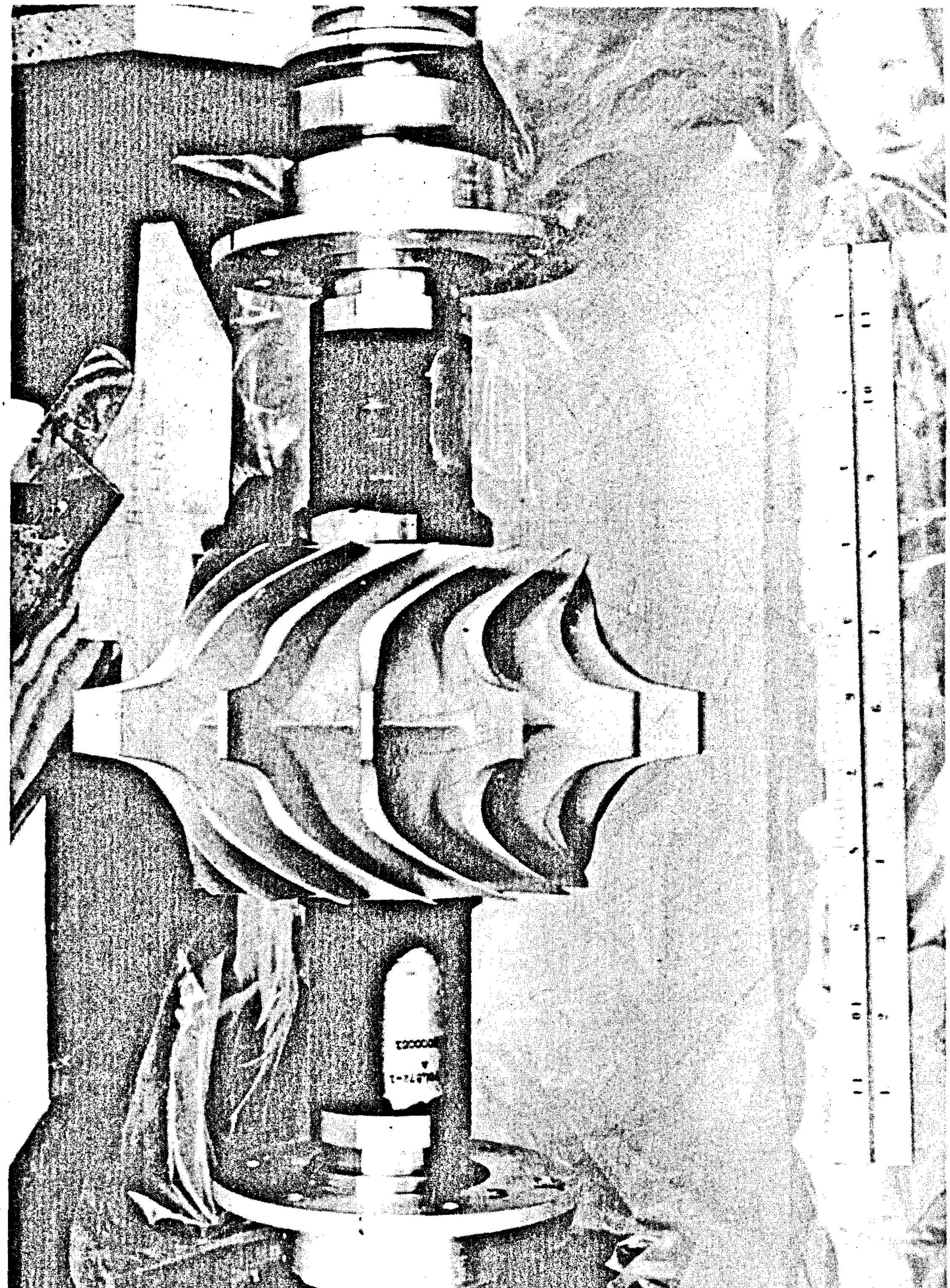


Fig. 3 Turbine Rotor

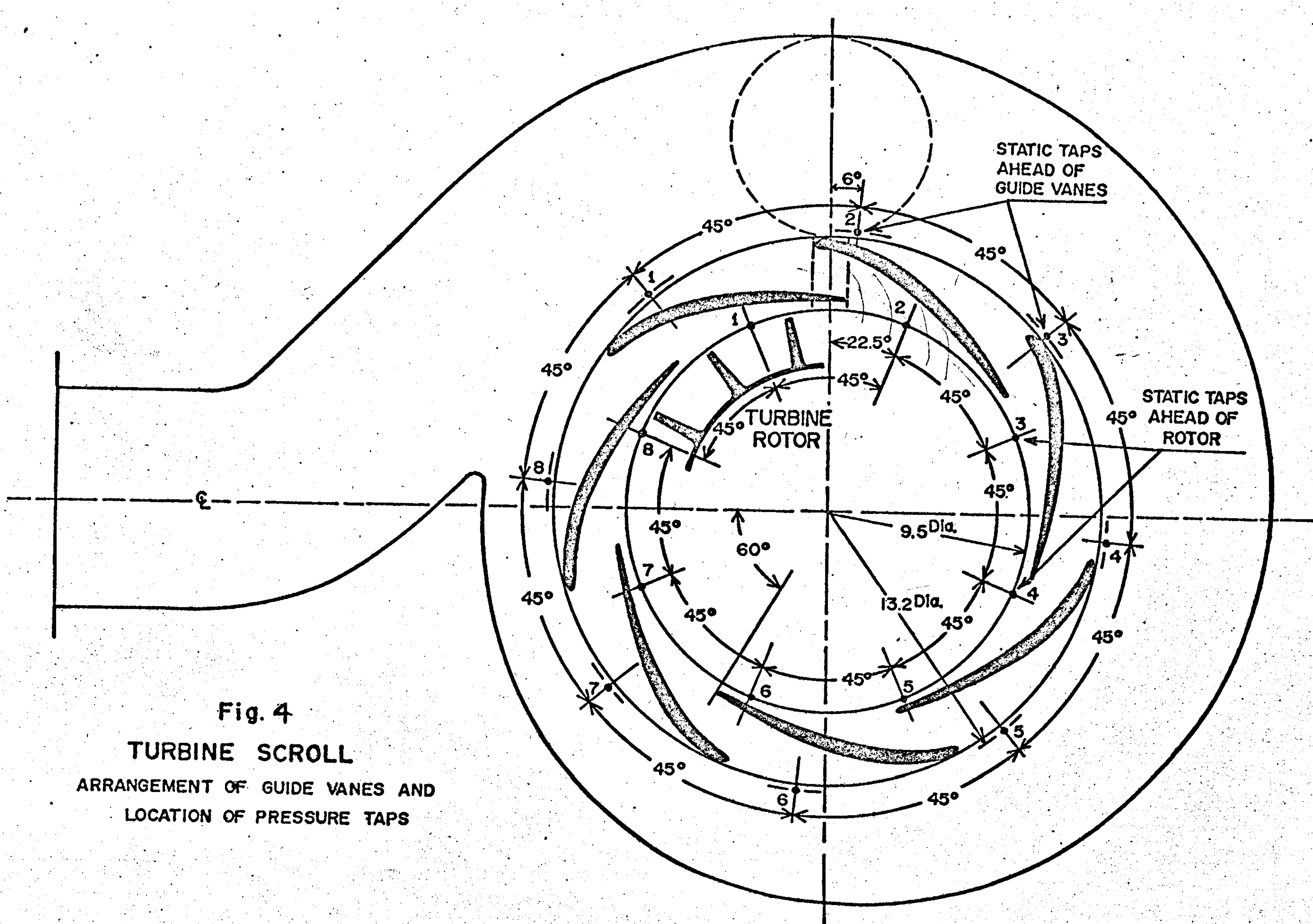


Fig. 4

TURBINE SCROLL

ARRANGEMENT OF GUIDE VANES AND LOCATION OF PRESSURE TAPS

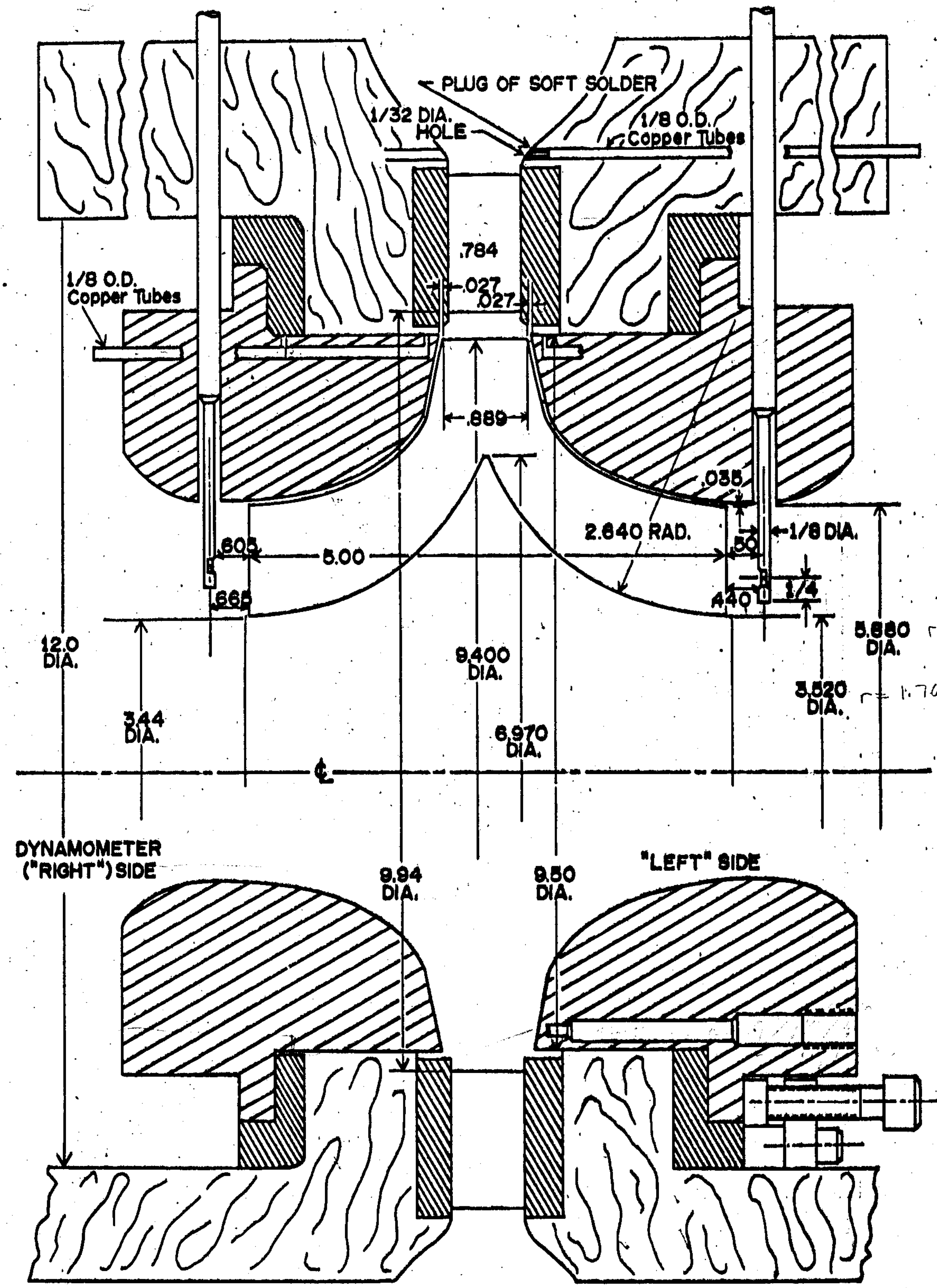


FIG. 5
CROSS SECTION OF TURBINE

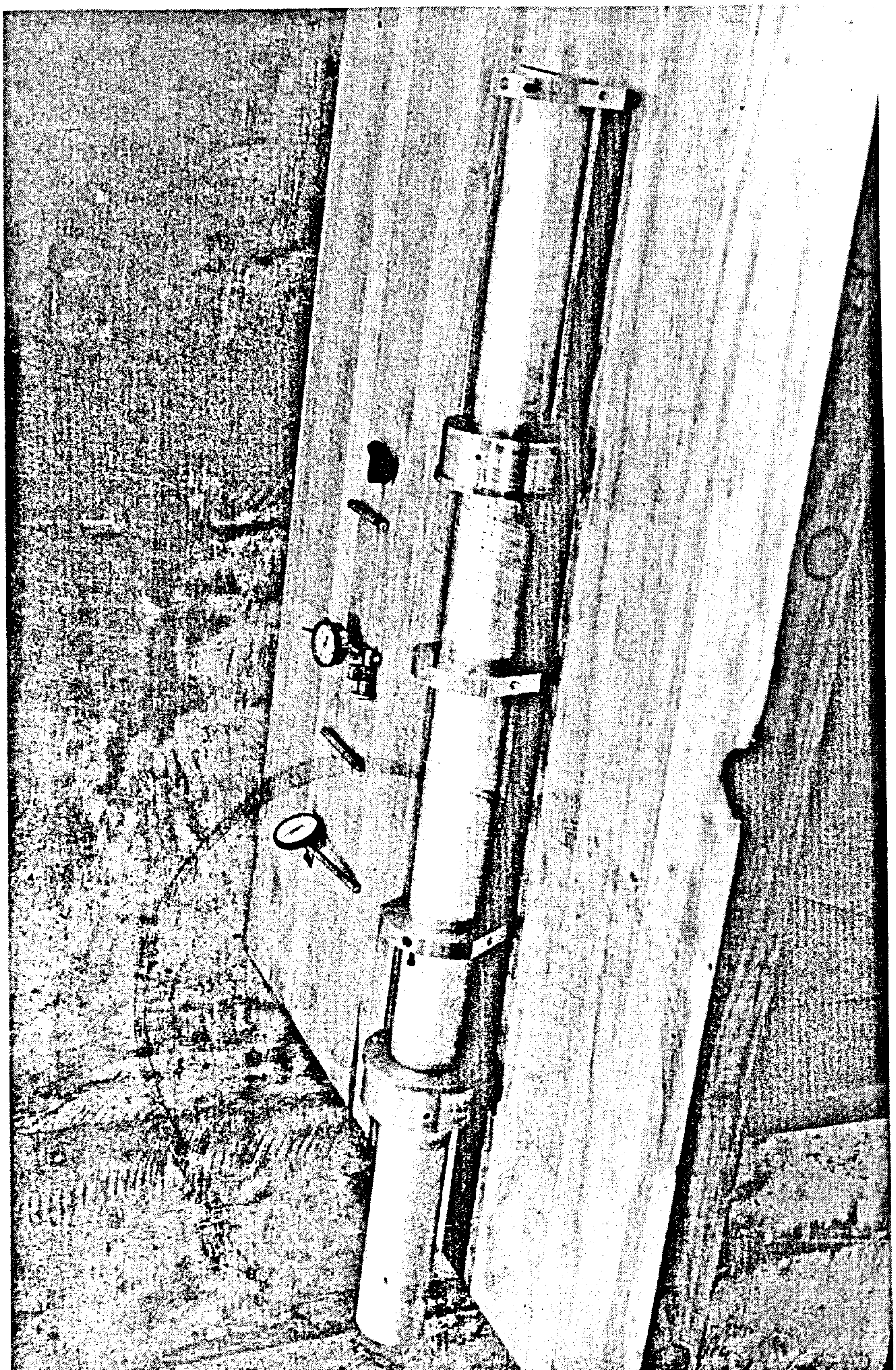


Fig. 6 Dummy Alignment Shaft

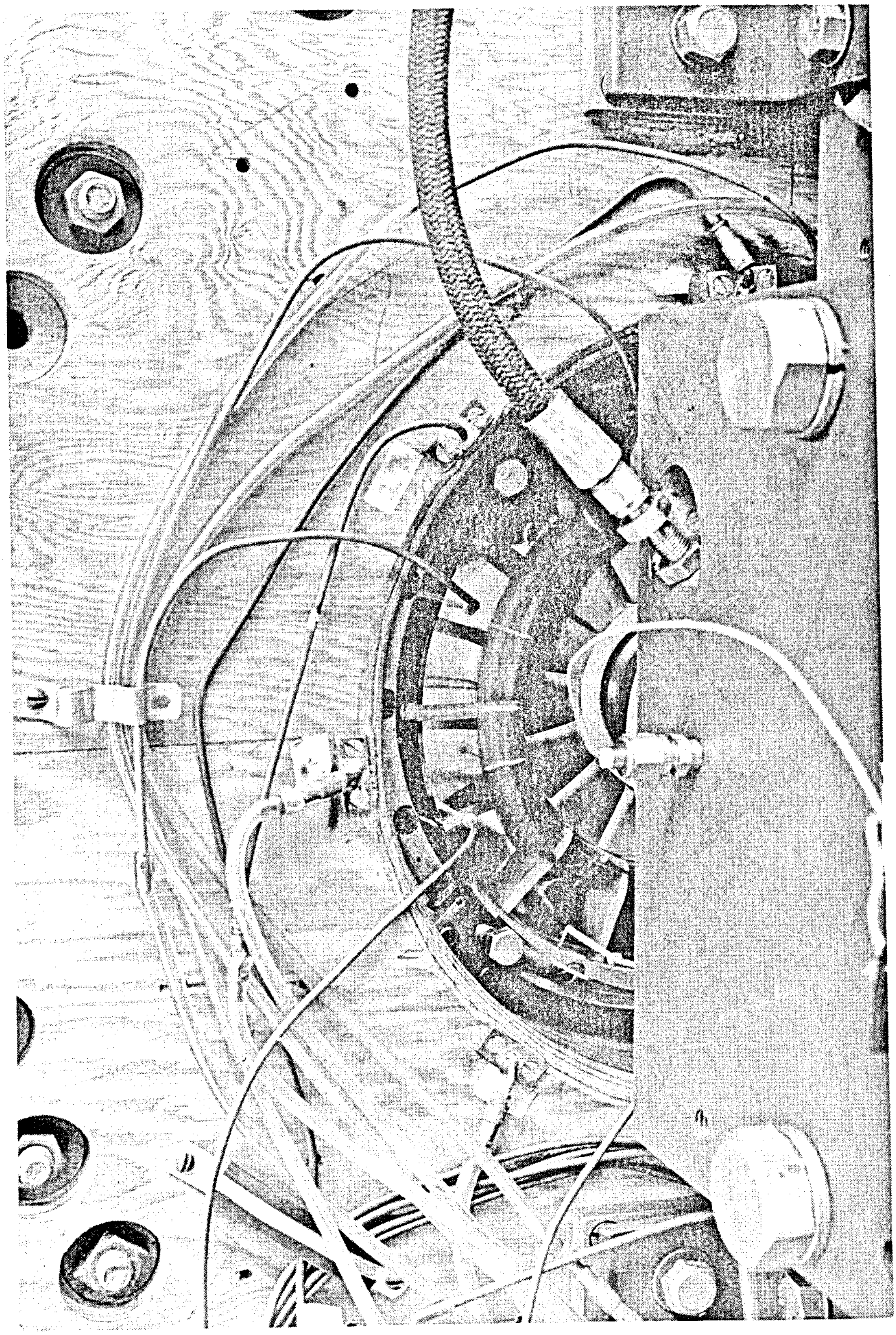


Fig. 7 Right Rotor Discharge

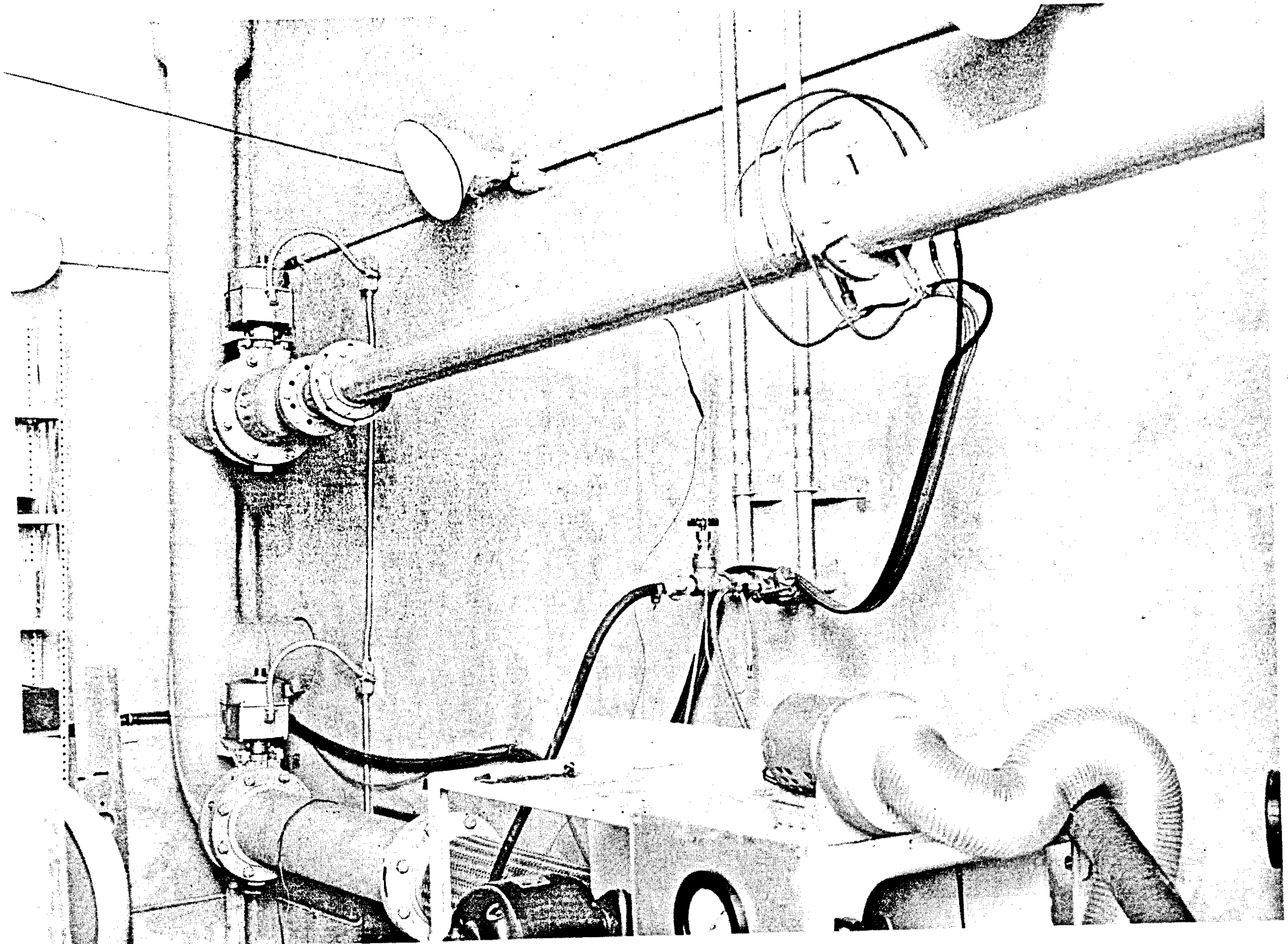


Fig. 8 Four Inch Pipe with Remote Controlled Inlet Valve and Measuring Orifice Pressure Taps

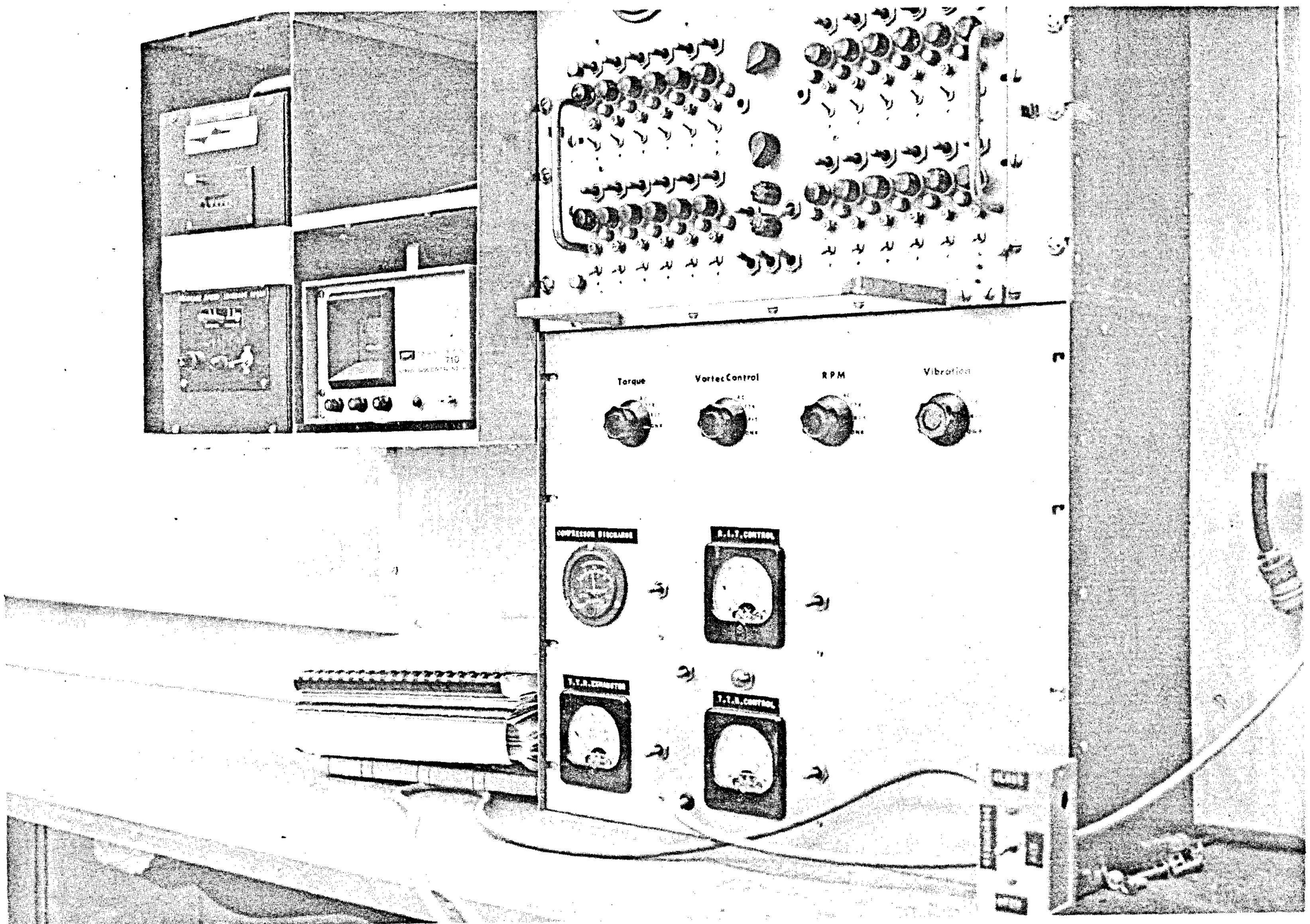


Fig. 9 Remote Control for Flow Regulation, Vortac Remote Throttle Control, and Daytonic Strain Gage Indicator

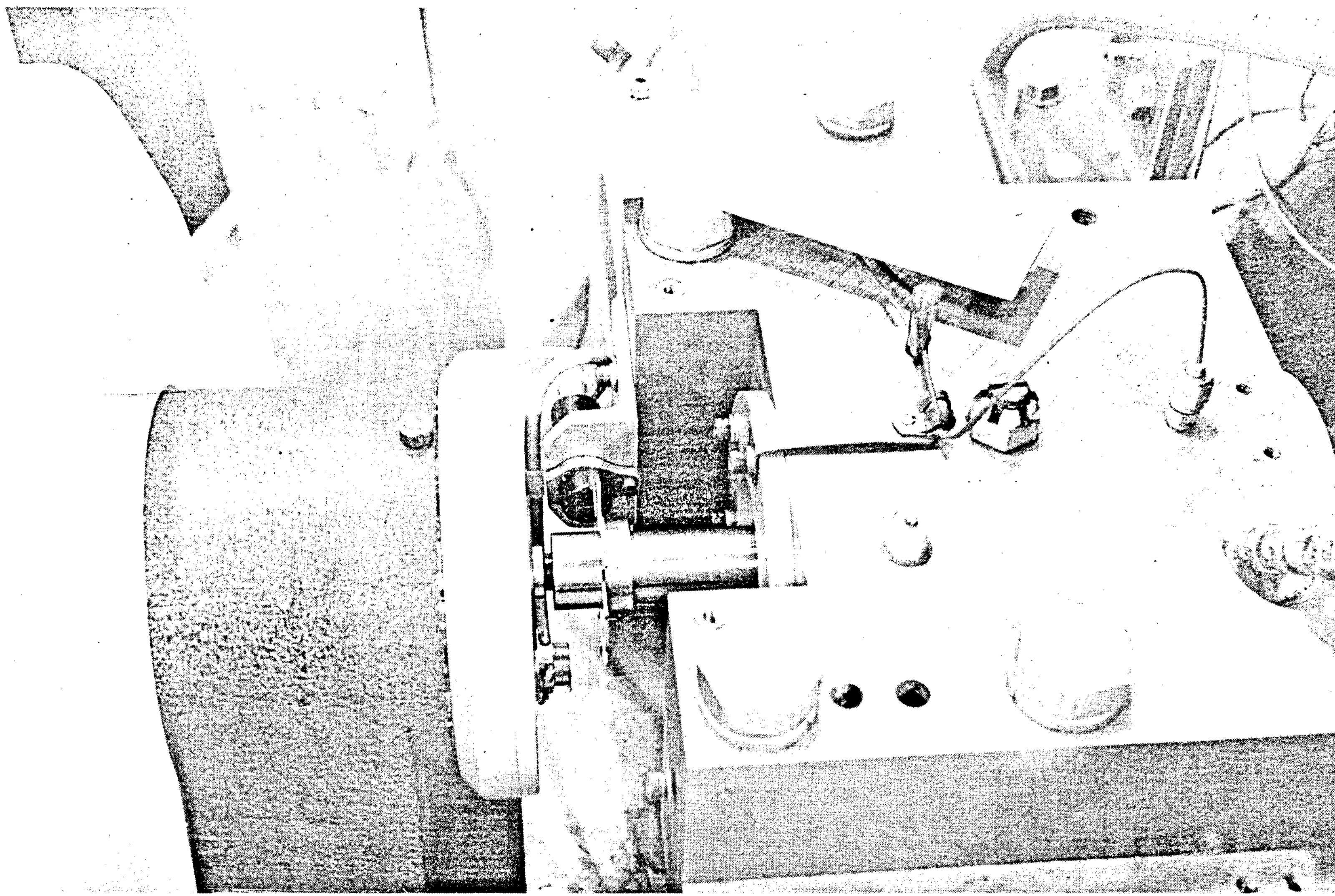


Fig. 10 Quill Shaft, Flux Cutter, and Dynamometer Torque Capsule

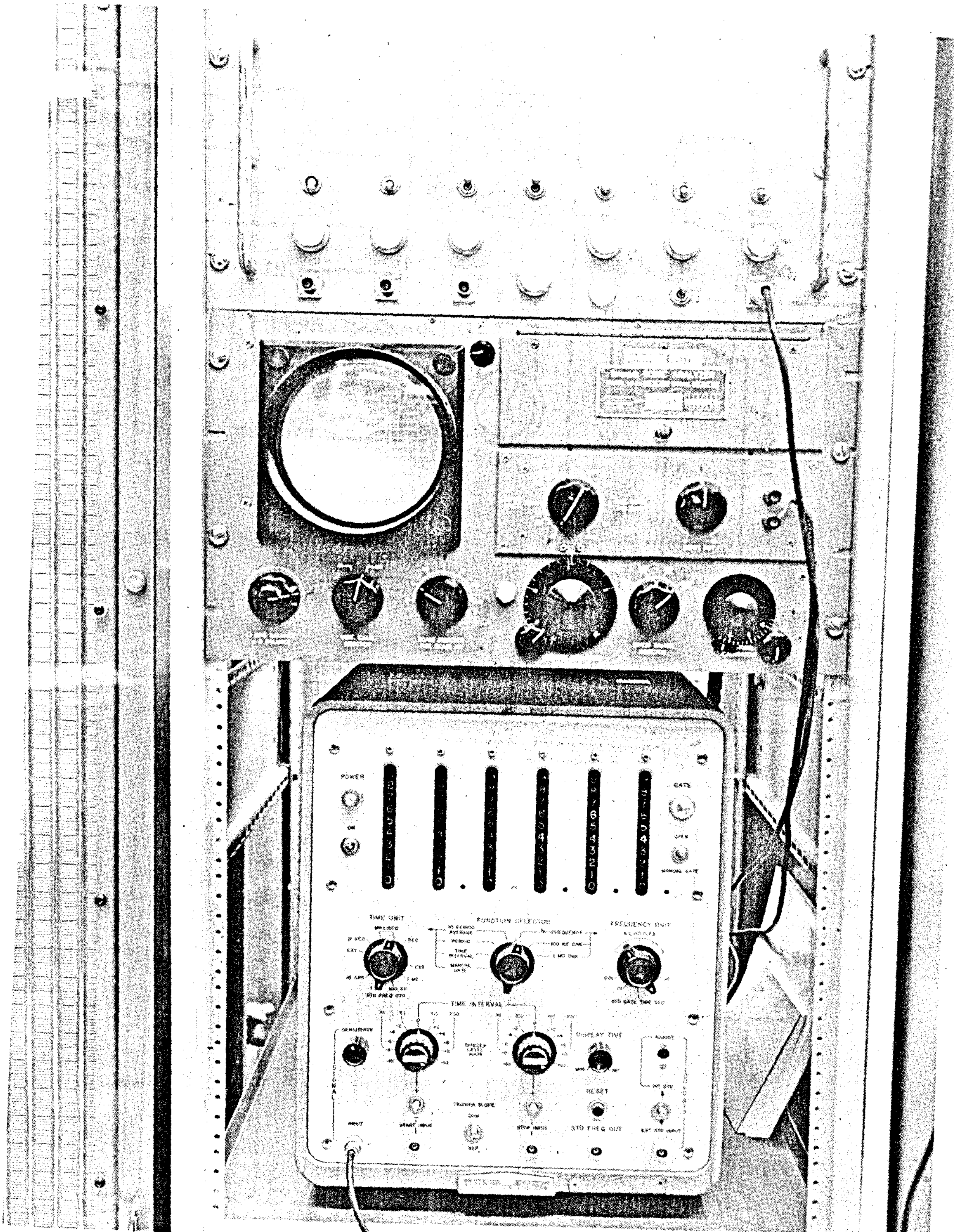
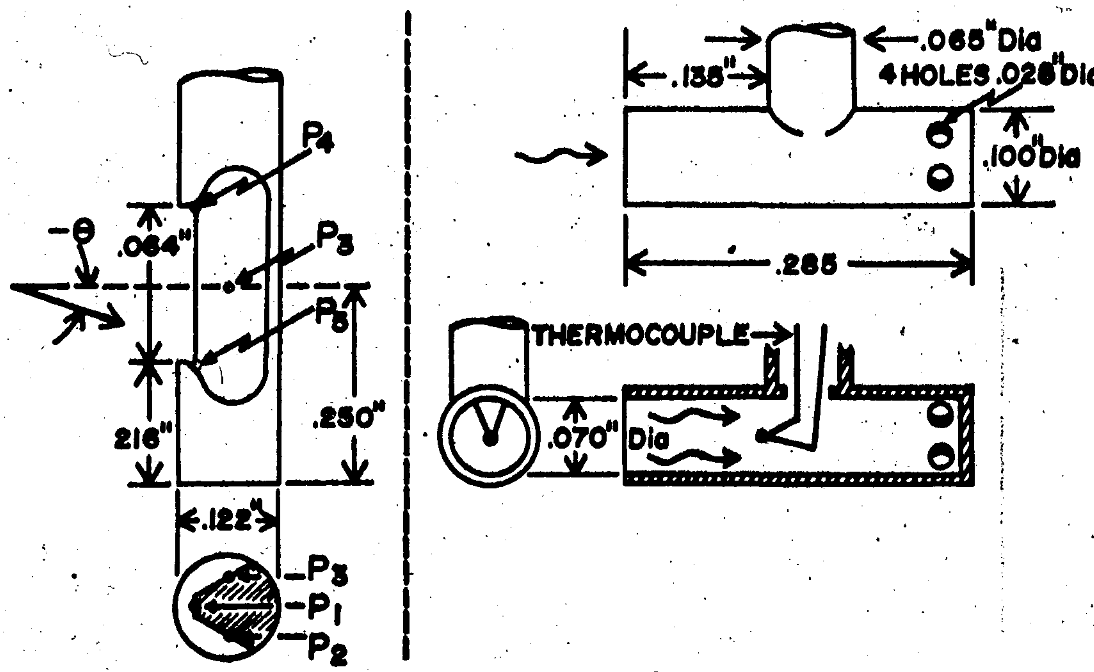


Fig. 11 Electronic Speed Counter and Vibration Analyzer



PRESSURE PROBE HEAD　　TEMPERATURE PROBE HEAD

FIG. 12
PRESSURE AND TEMPERATURE SURVEY PROBE HEADS

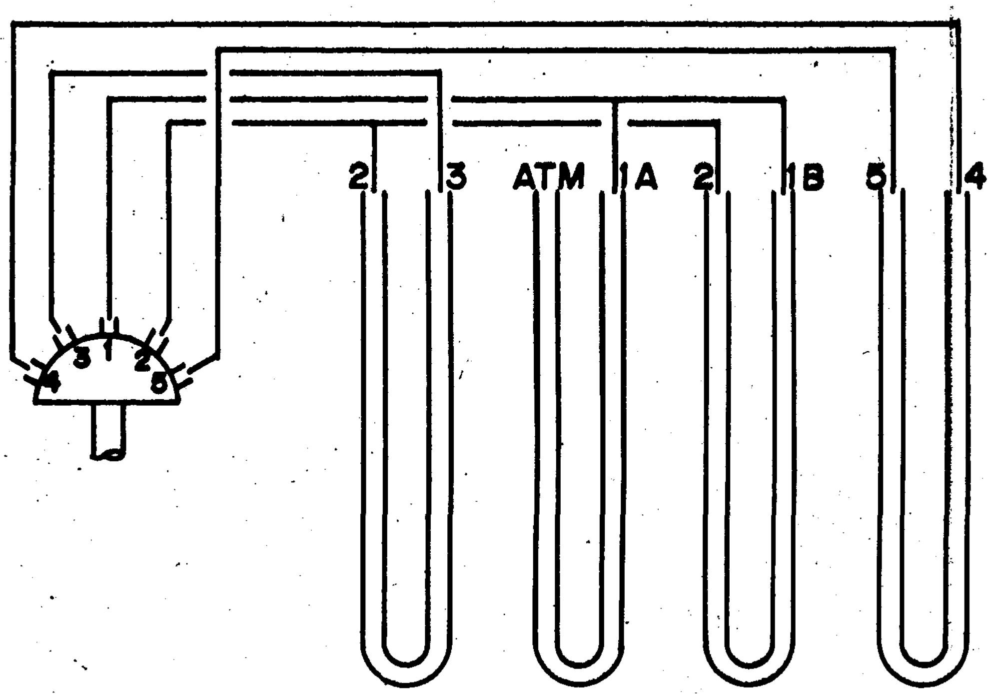


FIG. 13
TYPICAL DA-120 PRESSURE PROBE MANOMETER CONNECTION

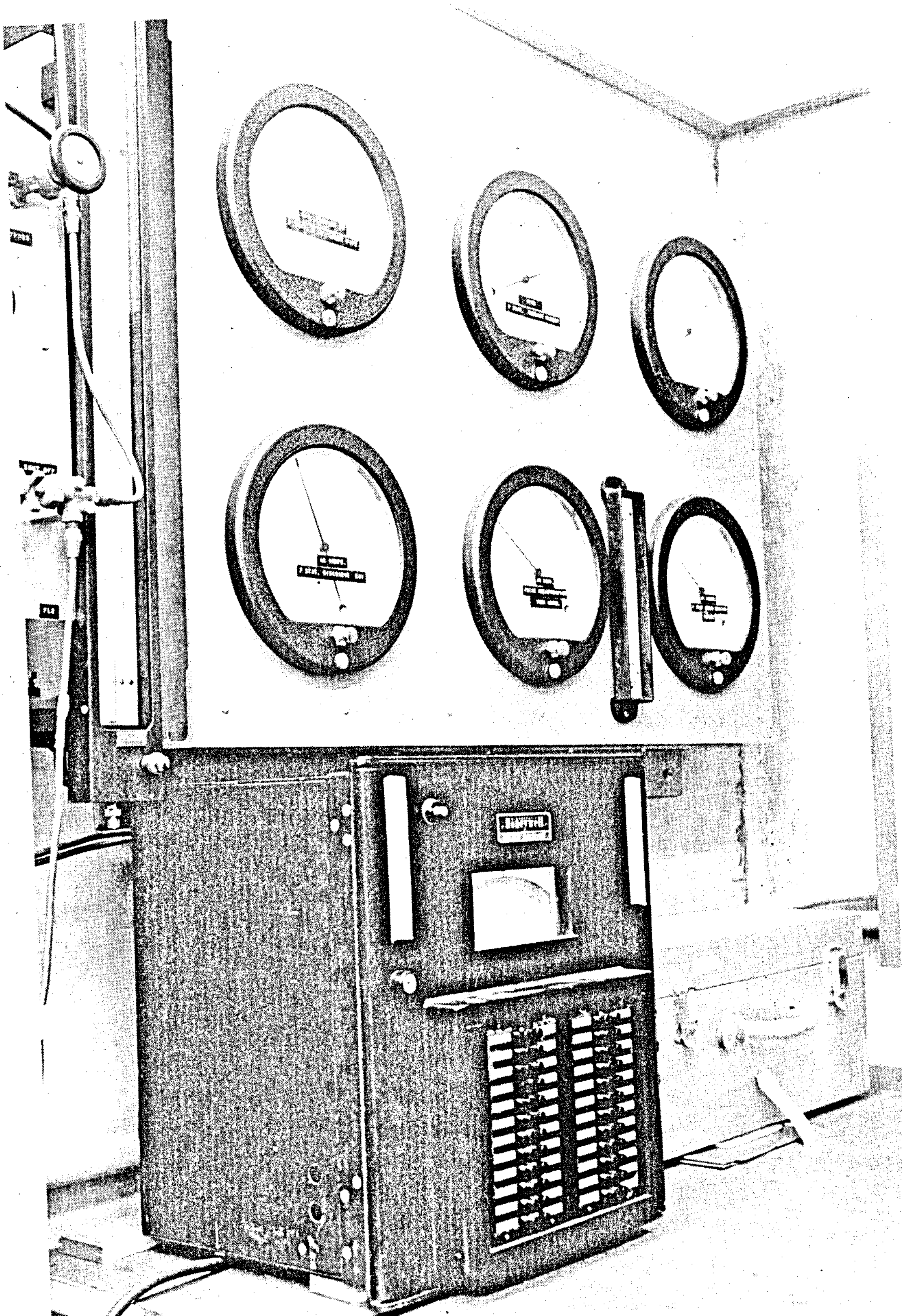


Fig. 14 Heise Gage and Brown Potentiometer

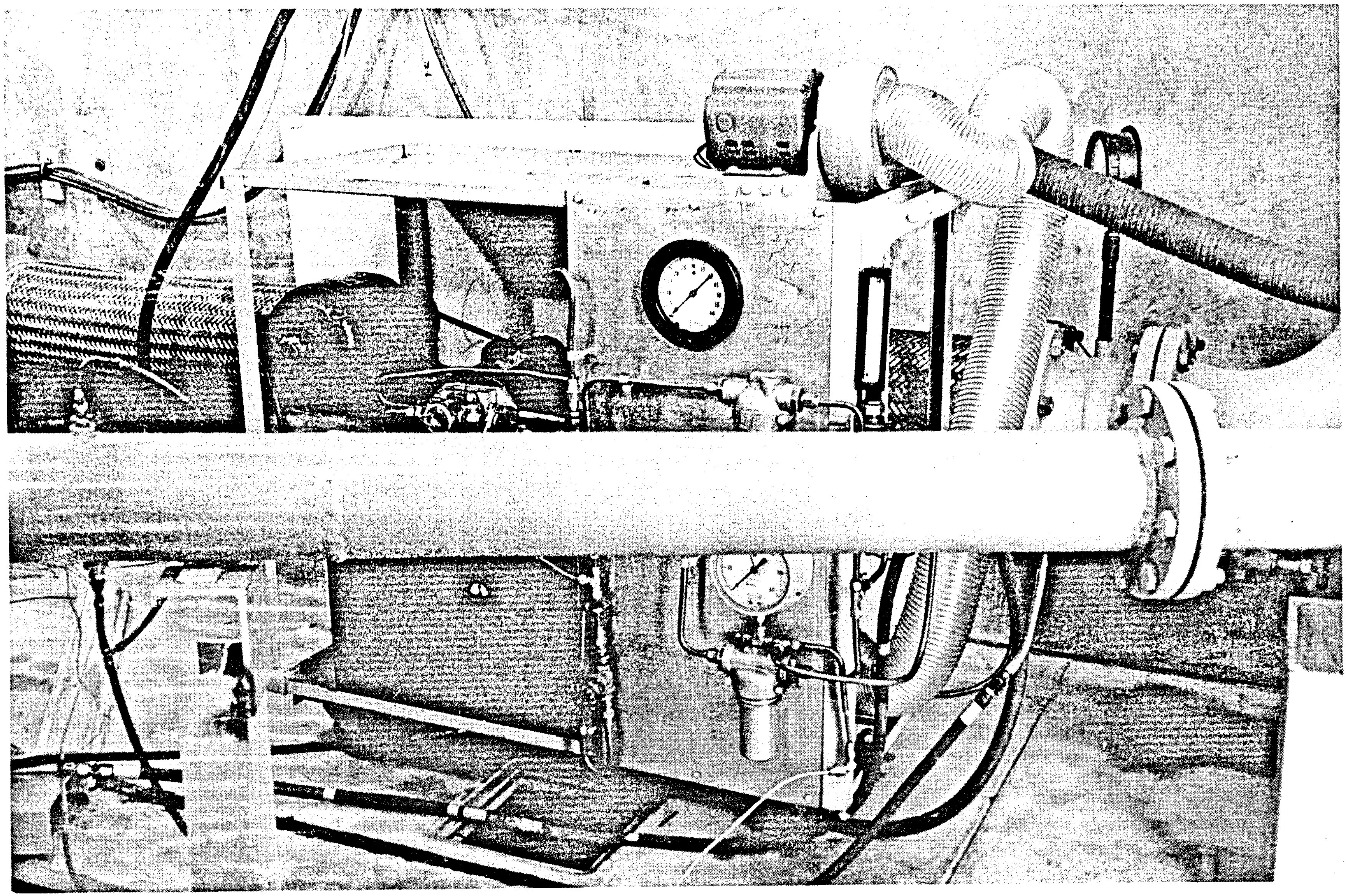


Fig. 15 Five Inch Inlet Pipe and Bearing Lubrication Unit

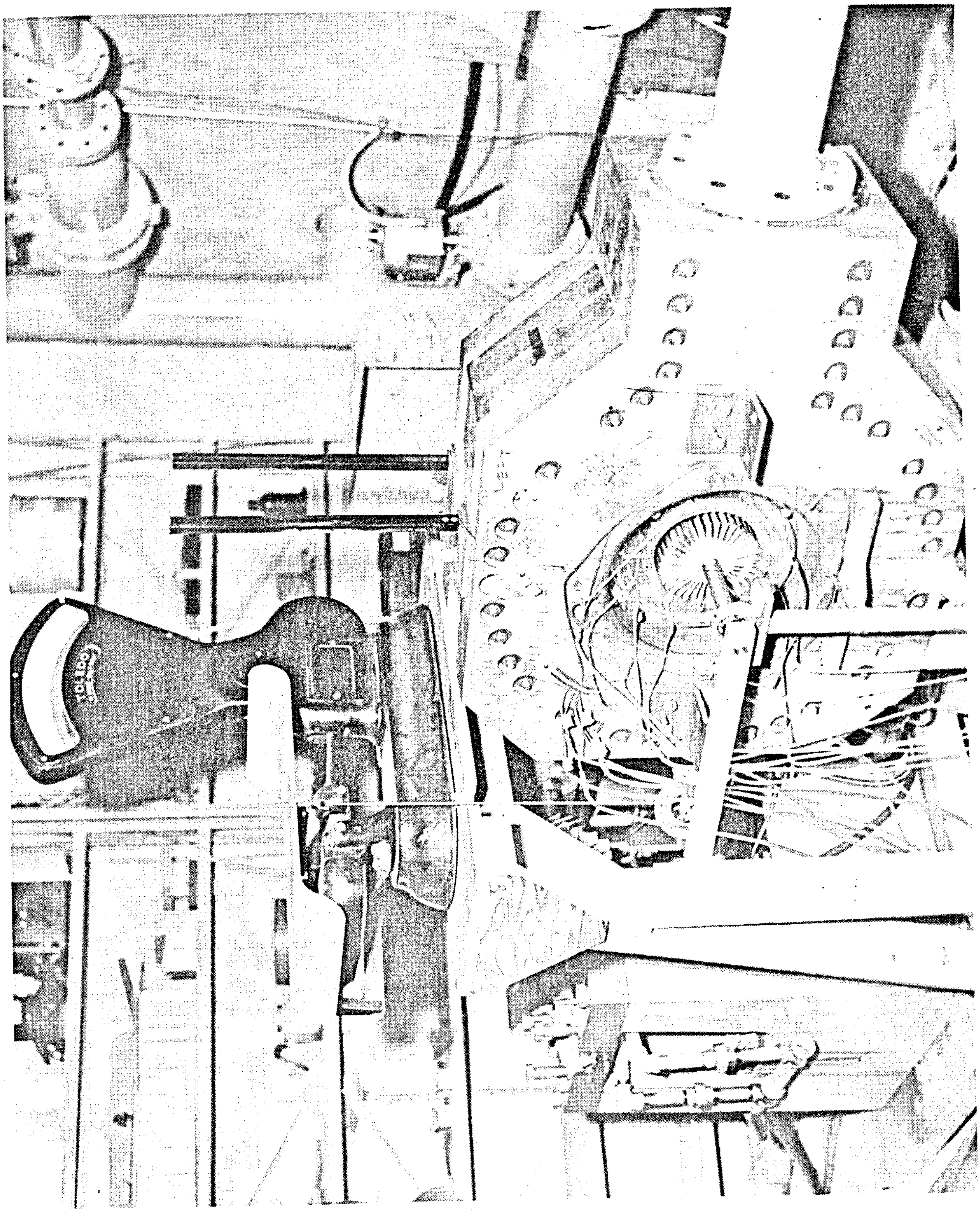


Fig. 16 Dummy Rotor Installation

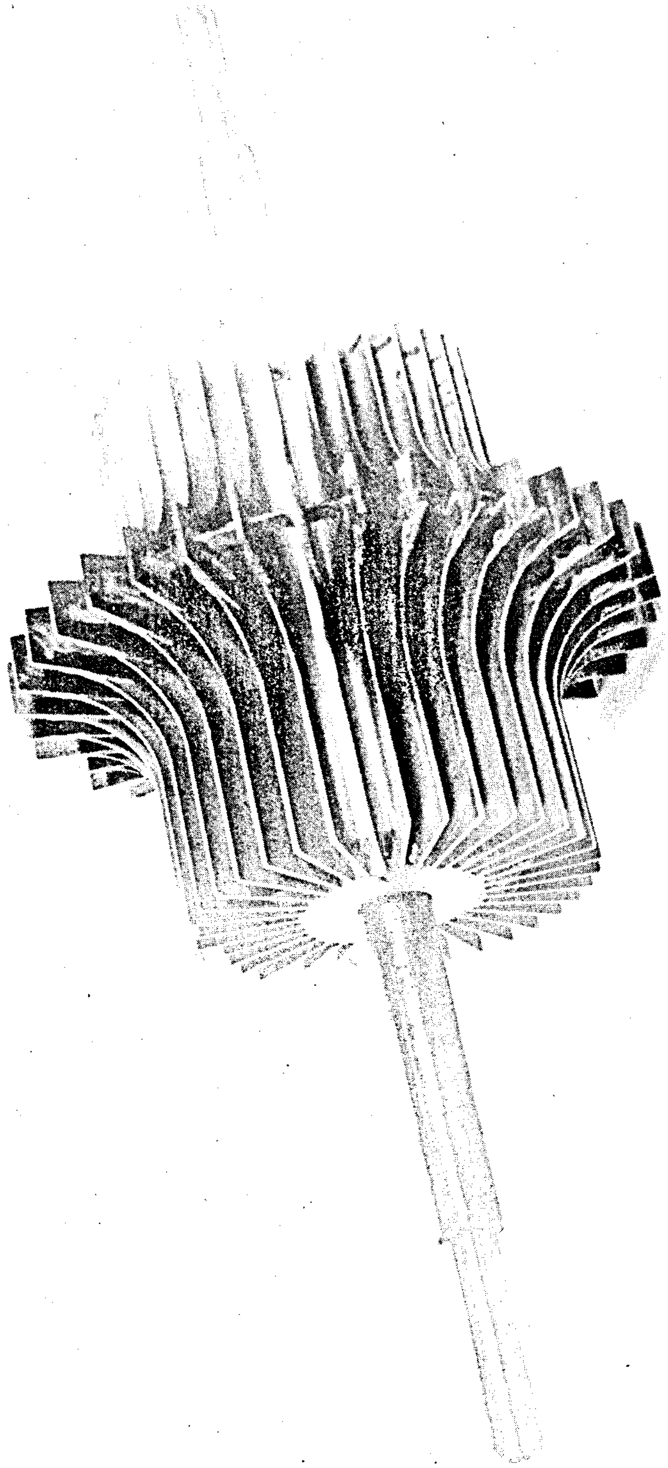


Fig. 17 Dummy Rotor

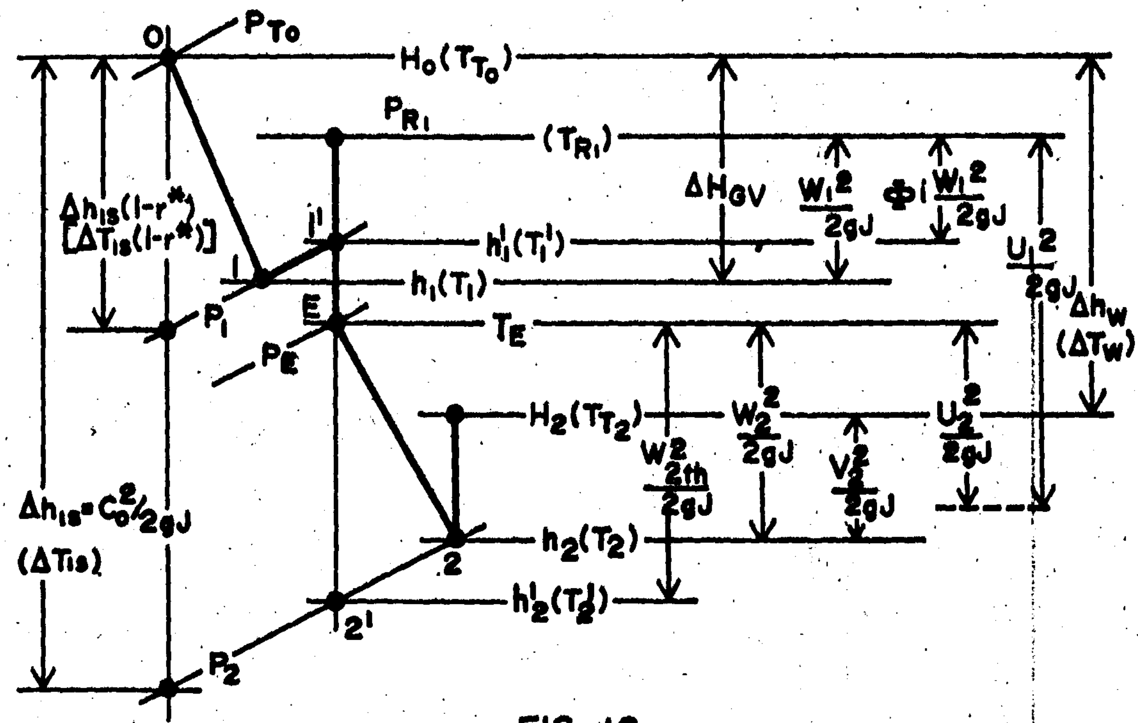
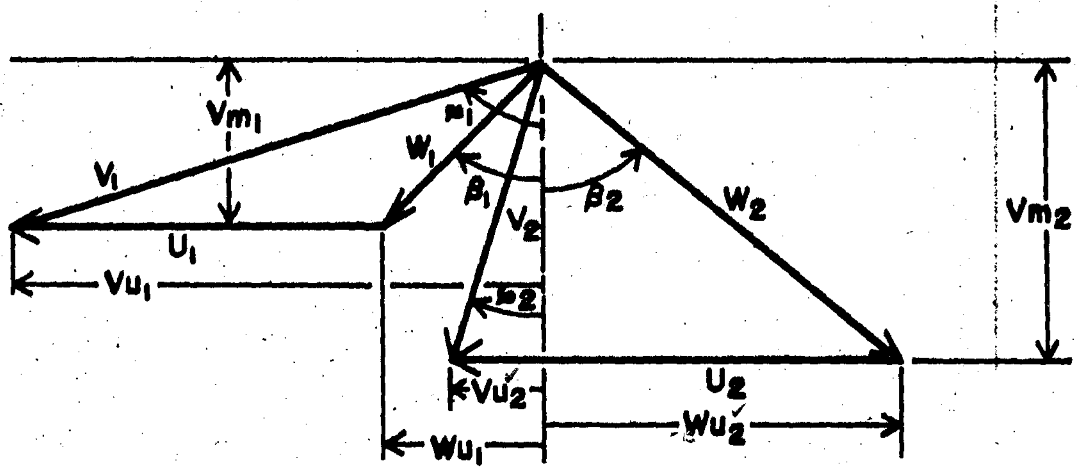


FIG. 18

ENTROPY DIAGRAM OF RADIAL TURBINE EXPANSION PROCESS



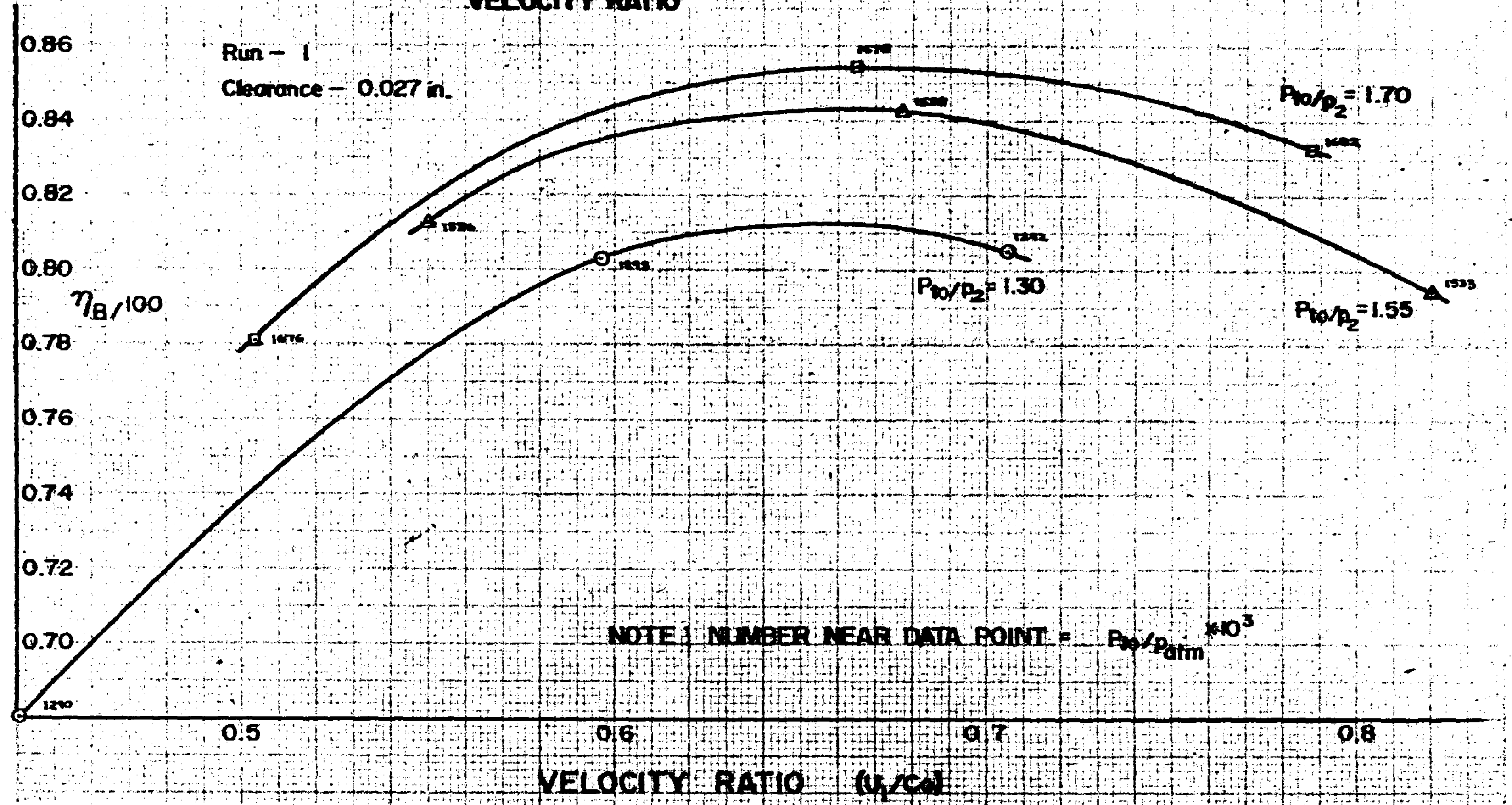
V = ABSOLUTE VELOCITY
W = RELATIVE VELOCITY
U = PERIPHERAL VELOCITY

FIG. 19

VELOCITY DIAGRAM

Fig. 20

BLADING EFFICIENCY (total to static) for MINIMUM BEARING LOSSES
vs
VELOCITY RATIO



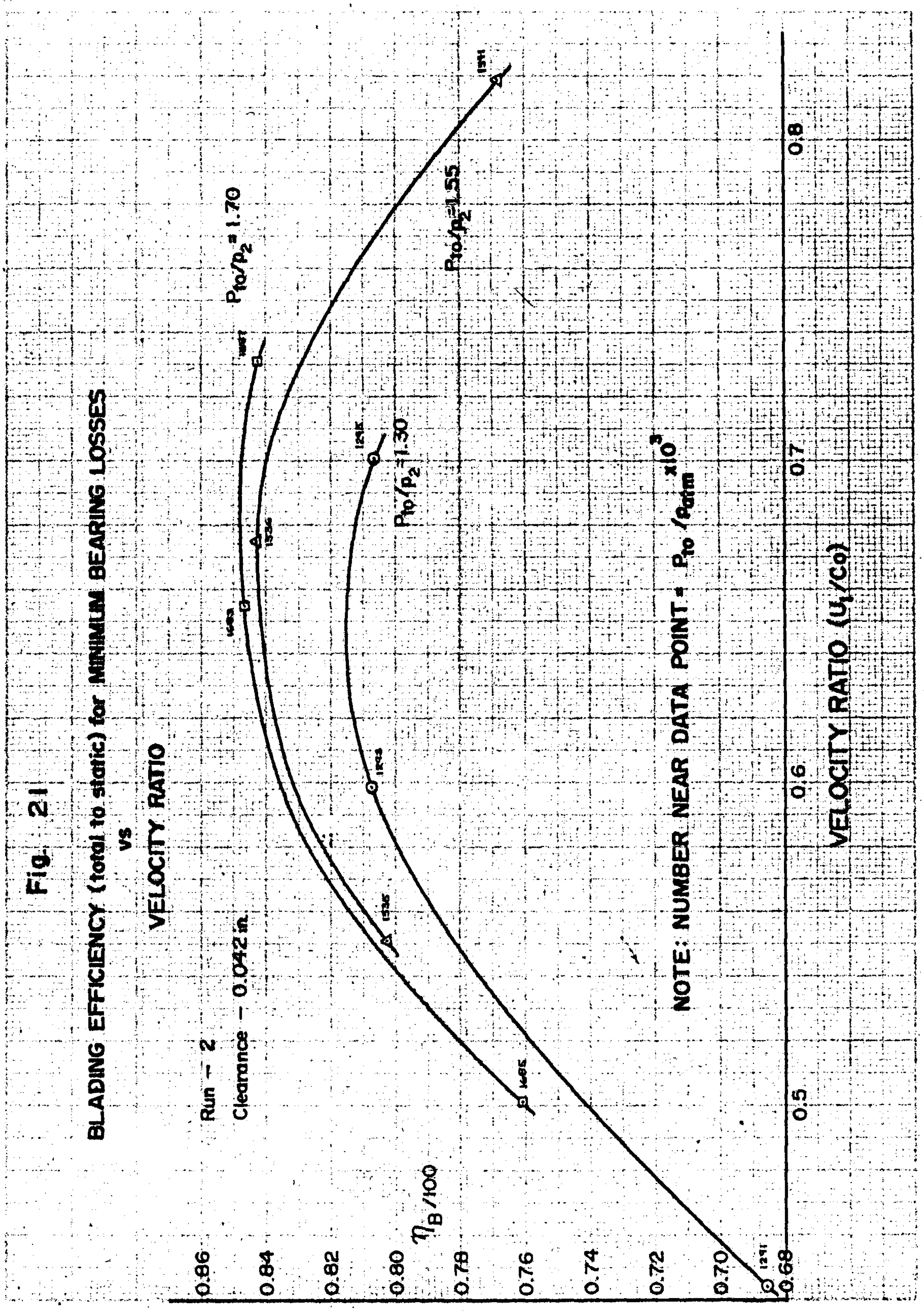
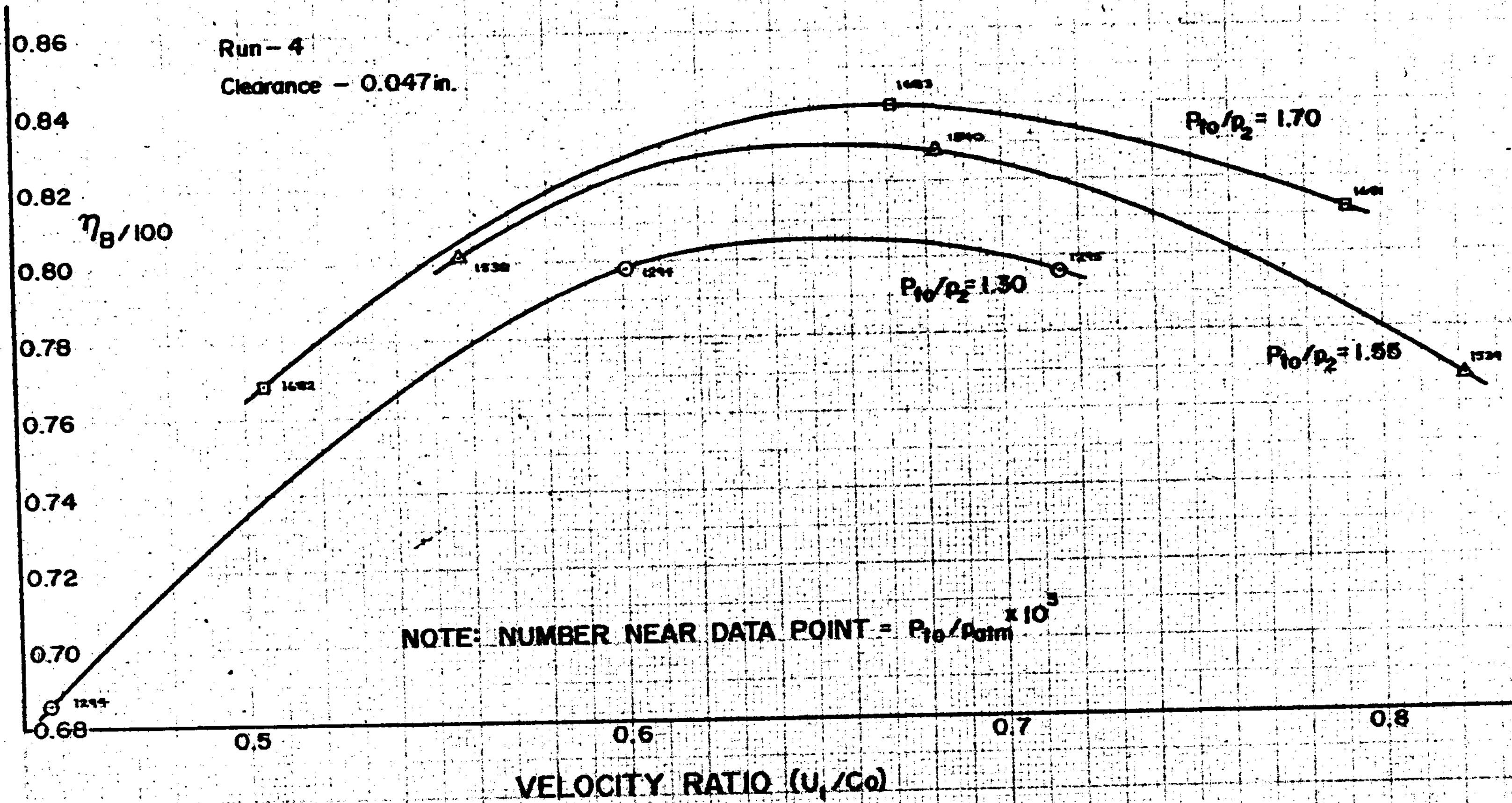


Fig. 21

BLADING EFFICIENCY (total to static) for MINIMUM BEARING LOSSES vs VELOCITY RATIO

Fig. 22

BLADING EFFICIENCY (total to static) for MINIMUM BEARING LOSSES
vs
VELOCITY RATIO



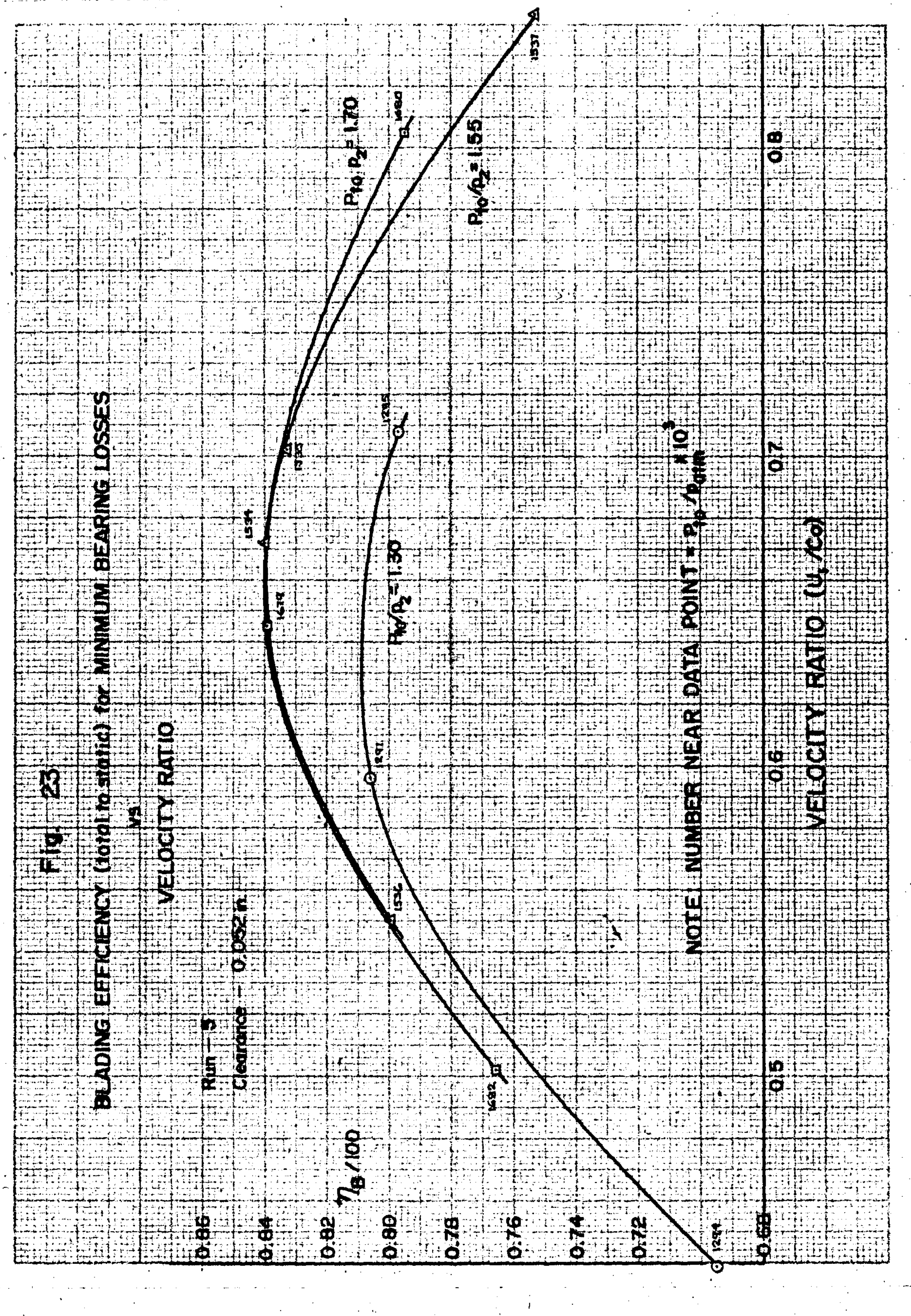
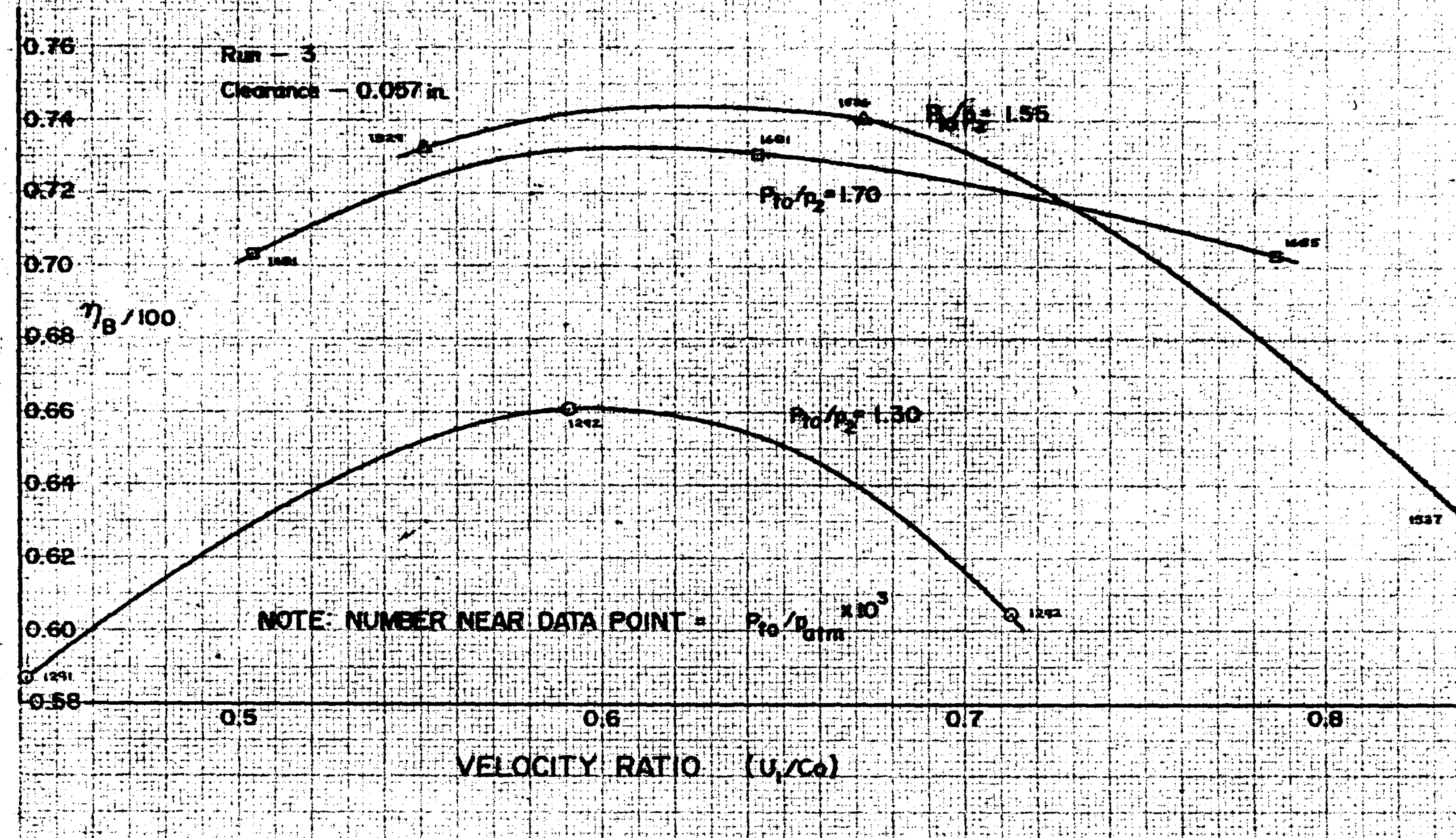


Fig. 23
BLADING EFFICIENCY (total to static) for MINIMUM BEARING LOSSES
vs
VELOCITY RATIO
Run — 5
Clearance — 0.052 in.
$\eta_B/100$
0.86
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.68
0.5
0.6
0.7
0.8
$P_{10}/P_2 = 1.70$
$P_{10}/P_2 = 1.55$
$P_{10}/P_2 = 1.30$
NOTE: NUMBER NEAR DATA POINT = $P_{10}/P_{atm} \times 10^3$
VELOCITY RATIO (U_1/C_0)

Fig. 24

BLADING EFFICIENCY (total to static) for MINIMUM BEARING LOSSES
vs
VELOCITY RATIO



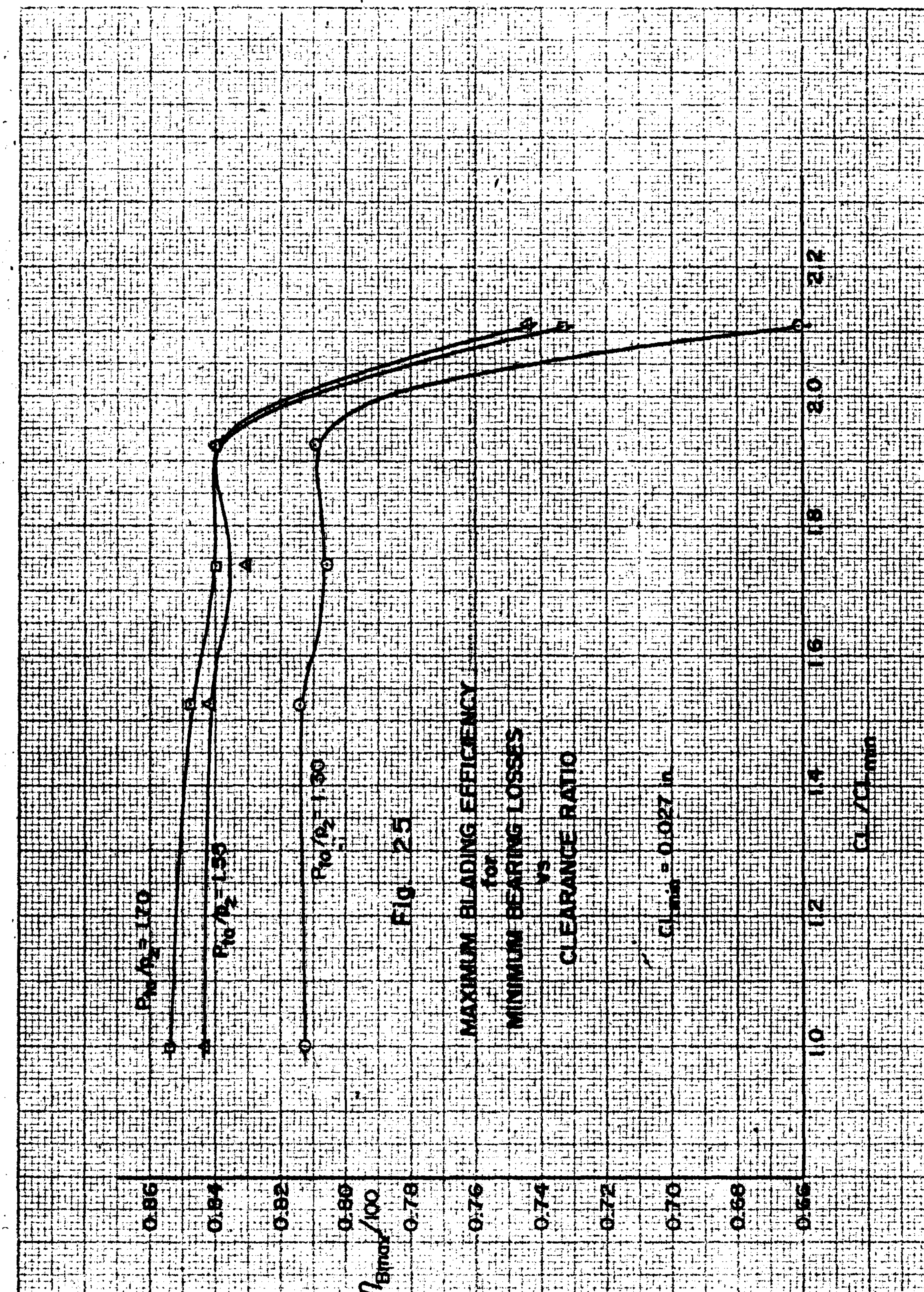


Fig. 25

MAXIMUM BLADING EFFICIENCY
for
MINIMUM BEARING LOSSES
vs
CLEARANCE RATIO

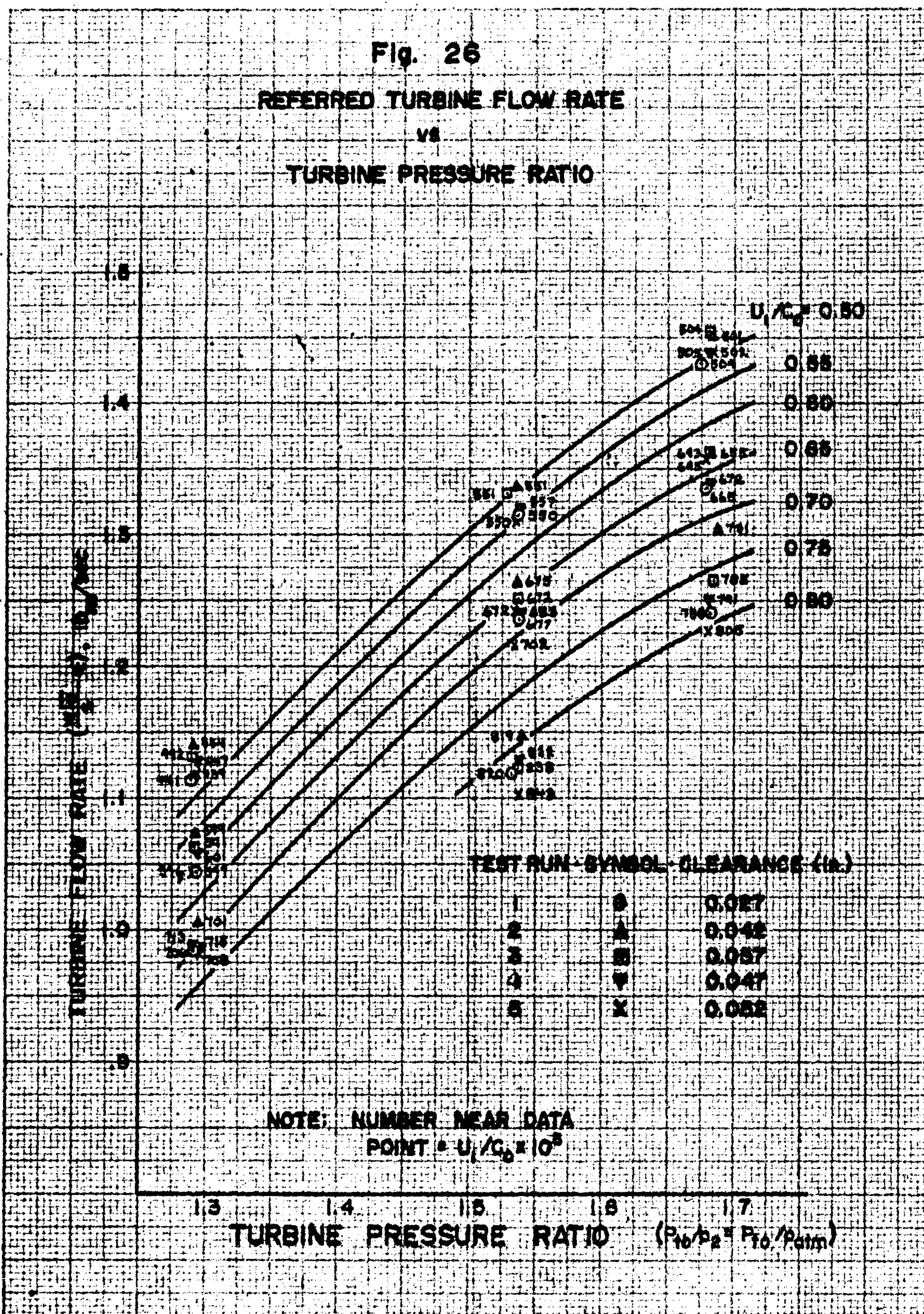


Fig. 26
REFERRED TURBINE FLOW RATE
vs
TURBINE PRESSURE RATIO
TEST RUN · SYMBOL · CLEARANCE (in.)
1 0.027
2 0.042
3 0.057
4 0.047
5 0.052
NOTE: NUMBER NEAR DATA
POINT = $U_i/C_0 \times 10^3$
TURBINE PRESSURE RATIO ($P_{t0}/p_2 = P_{t0}/P_{atm}$)
TURBINE FLOW RATE

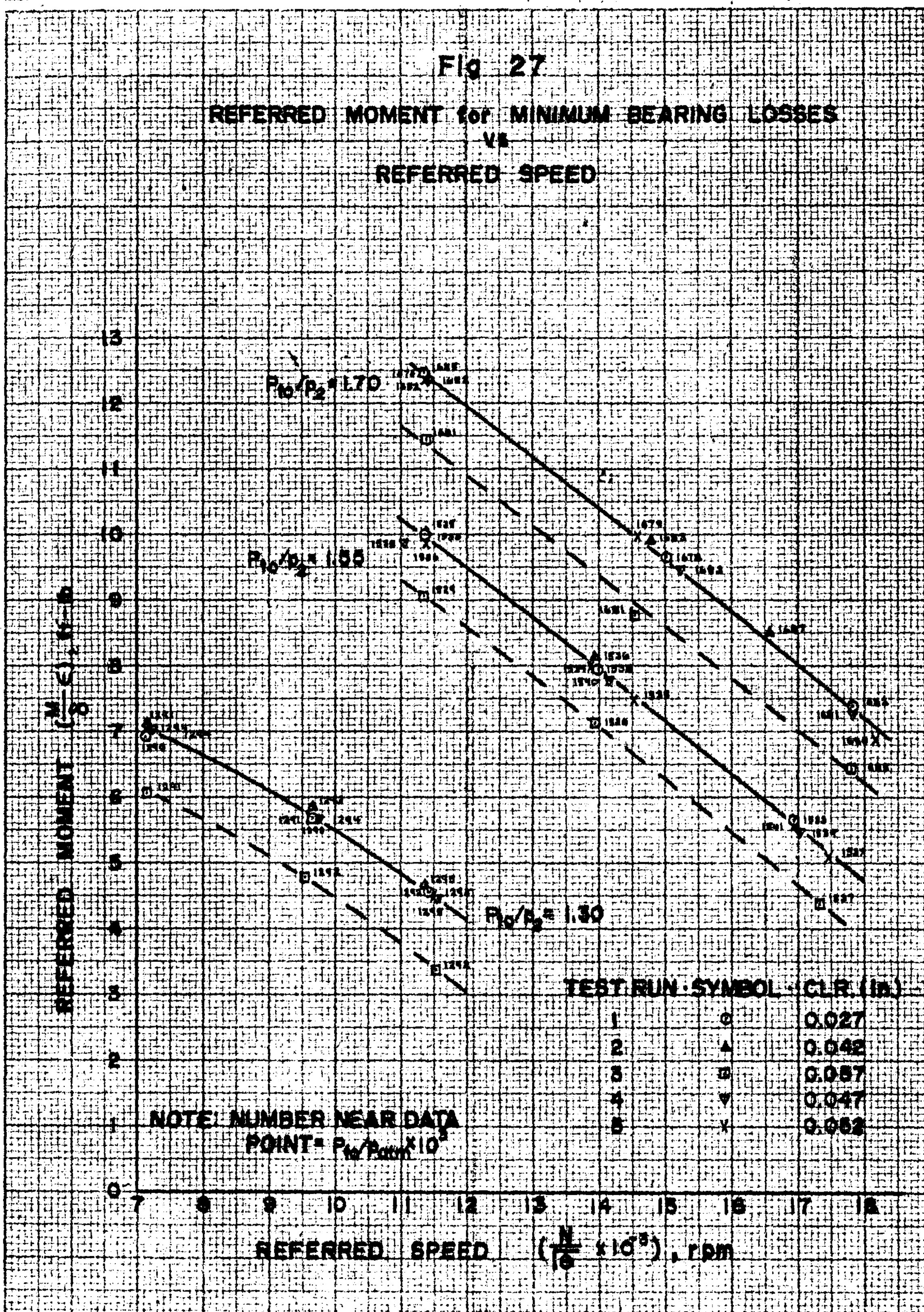


Fig 27
REFERRED MOMENT for MINIMUM BEARING LOSSES
VS
REFERRED SPEED
P10/P2 = 1.70
P10/P2 = 1.55
P10/P2 = 1.30
TEST RUN SYMBOL CLR (in)
1 0.027
2 0.042
3 0.057
4 0.047
5 0.052
NOTE: NUMBER NEAR DATA POINT = P10/Patm x 10
REFERRED MOMENT
REFERRED SPEED
rpm

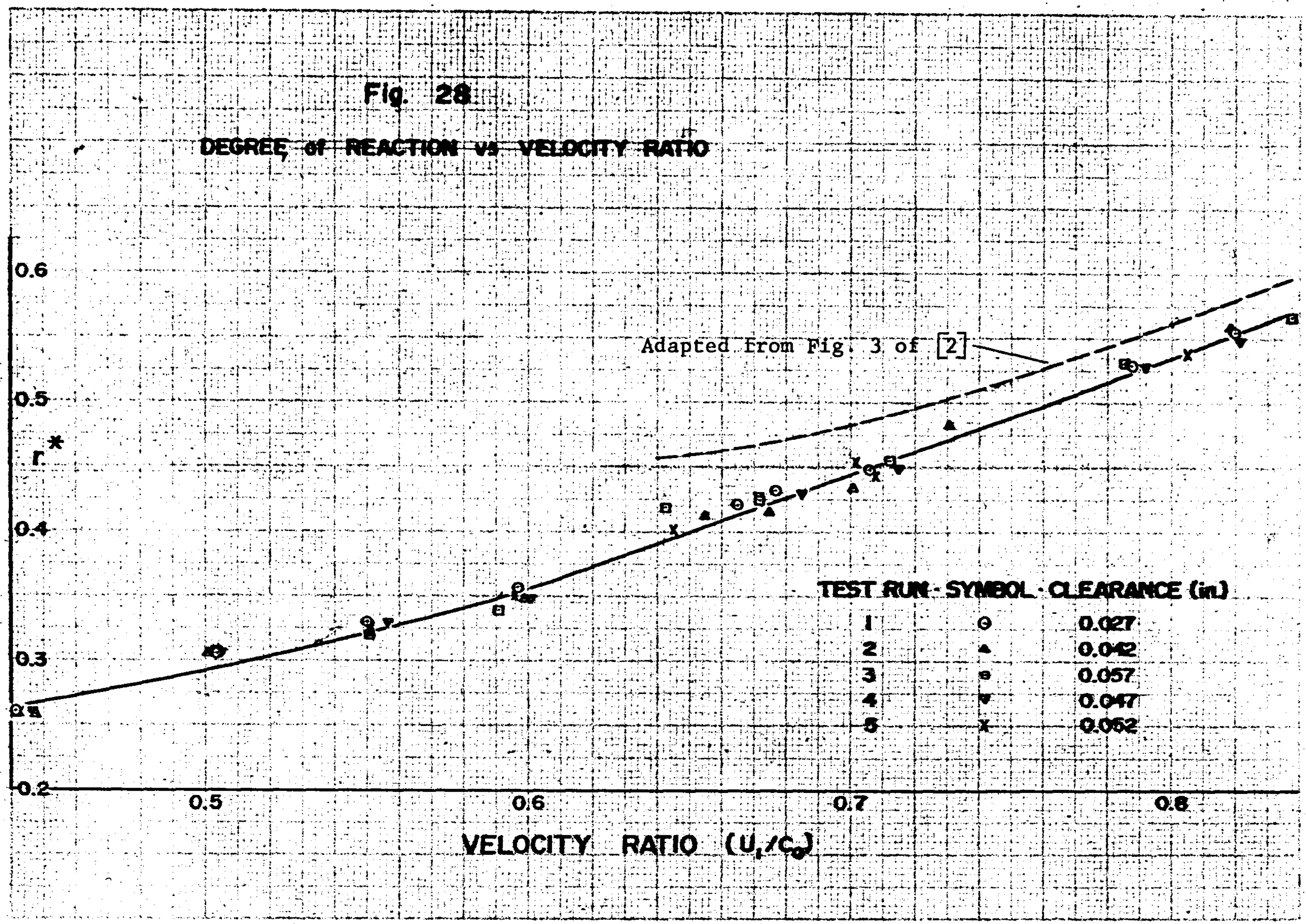


Fig. 28
DEGREE of REACTION vs VELOCITY RATIO
Adapted from Fig. 3 of [2]
r*
0.6
0.5
0.4
0.3
0.2
0.5
0.6
0.7
0.8
VELOCITY RATIO (U1/C0)
TEST RUN · SYMBOL · CLEARANCE (in.)
1 0.027
2 0.042
3 0.057
4 0.047
5 X 0.062

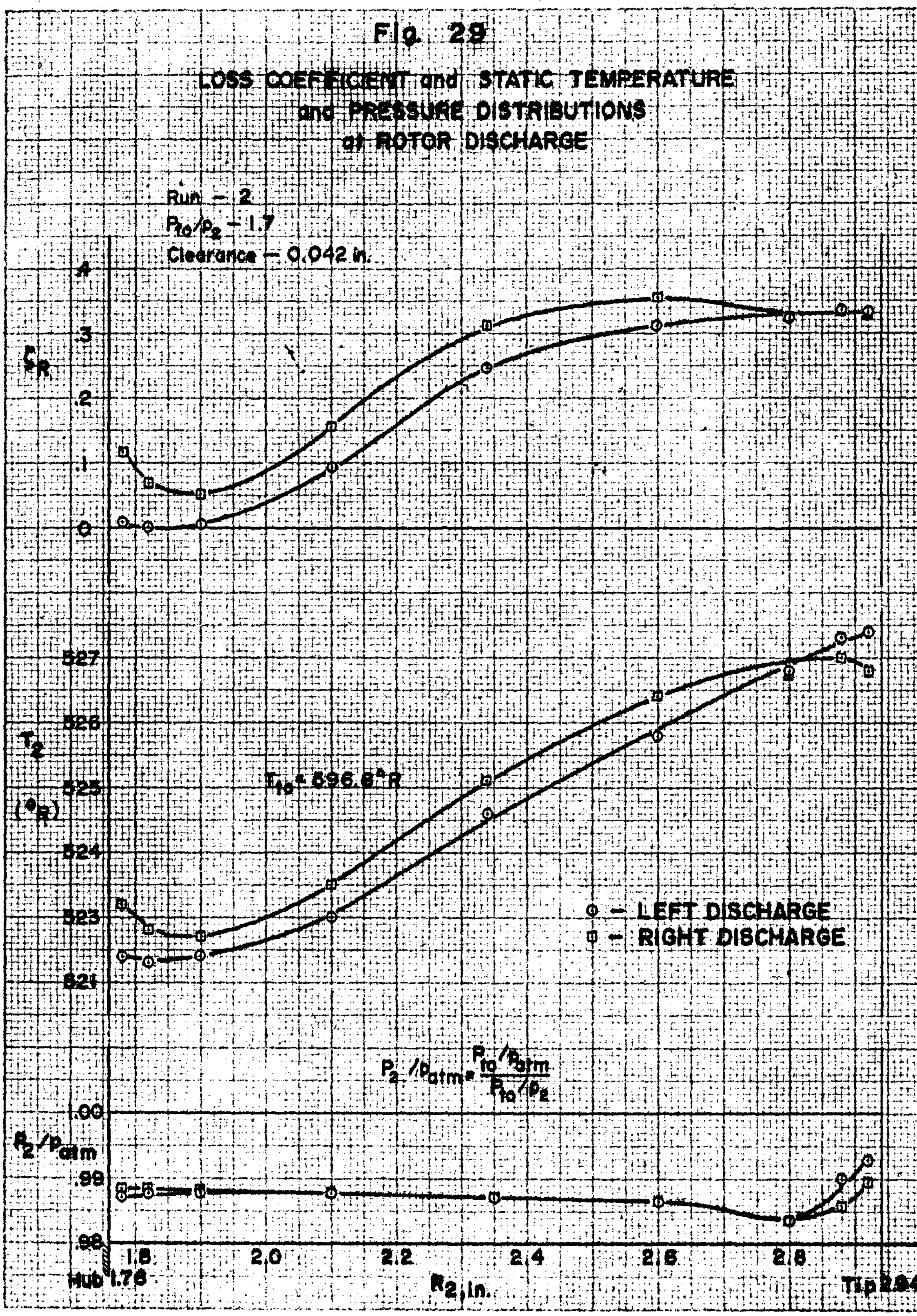


Fig. 29
LOSS COEFFICIENT and STATIC TEMPERATURE
and PRESSURE DISTRIBUTIONS
at ROTOR DISCHARGE
Run — 2
P_{to}/p_2 — 1.7
Clearance — 0.042 in.
ζ_R
T_2 (°R)
T_{to} = 596.8°R
○ — LEFT DISCHARGE
□ — RIGHT DISCHARGE
$P_2/p_{atm} = \frac{P_{to}/p_{atm}}{P_{to}/p_2}$
P_2/p_{atm}
Hub 1.76
R_2, in.
Tip 2.94

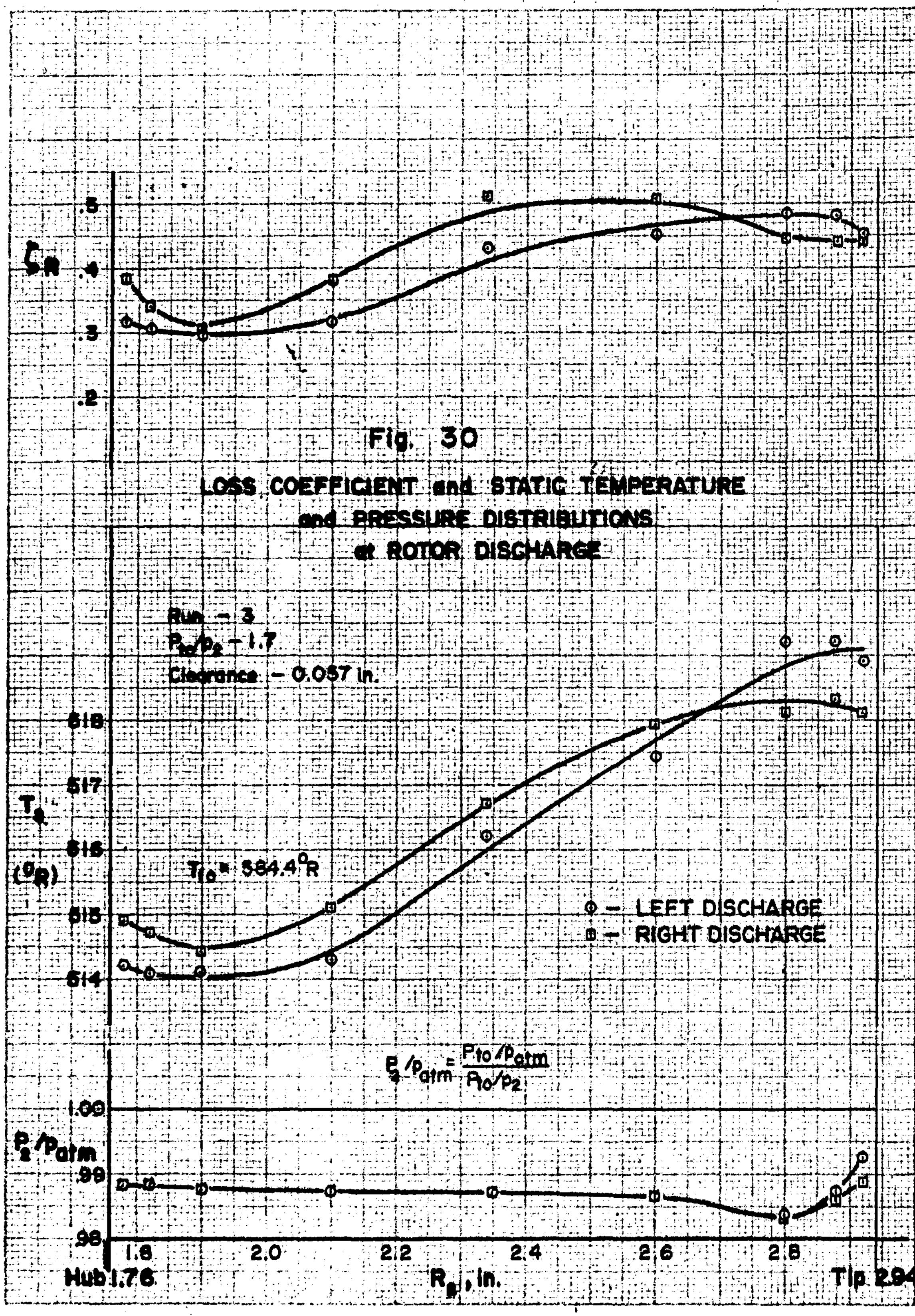


Fig. 30

LOSS COEFFICIENT and STATIC TEMPERATURE and PRESSURE DISTRIBUTIONS at ROTOR DISCHARGE

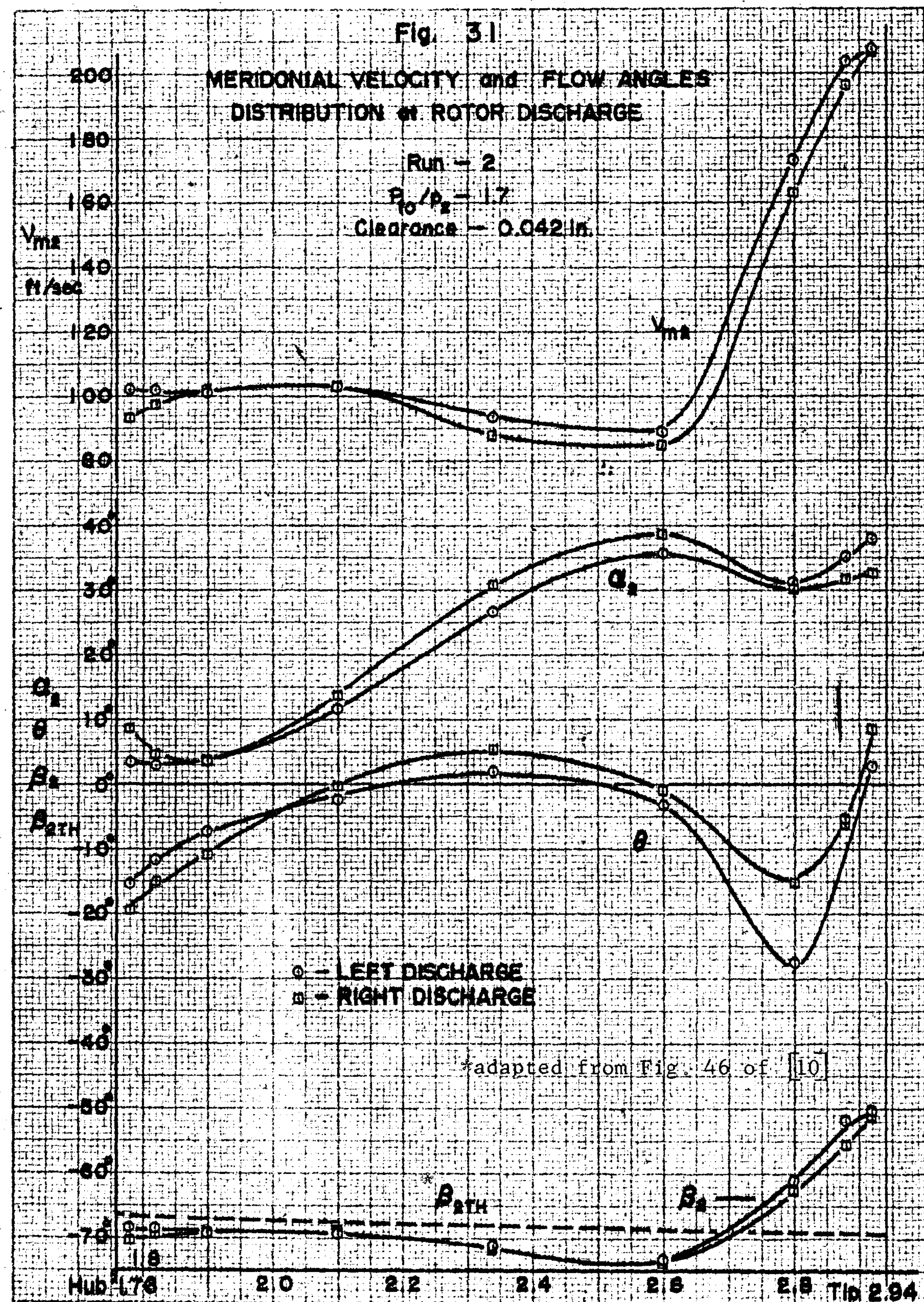


Fig. 31
MERIDONIAL VELOCITY and FLOW ANGLES
DISTRIBUTION at ROTOR DISCHARGE
Run — 2
P_{to}/p_2 — 1.7
Clearance — 0.042 in.
V_{m2}
ft/sec
α_2
θ
β_2
β_{2TH}
⊙ — LEFT DISCHARGE
⊡ — RIGHT DISCHARGE
*adapted from Fig. 46 of [10]
$^*\beta_{2TH}$
Hub 1.78
2.0
2.2
2.4
2.6
2.8
Tip 2.94
R_2, in.

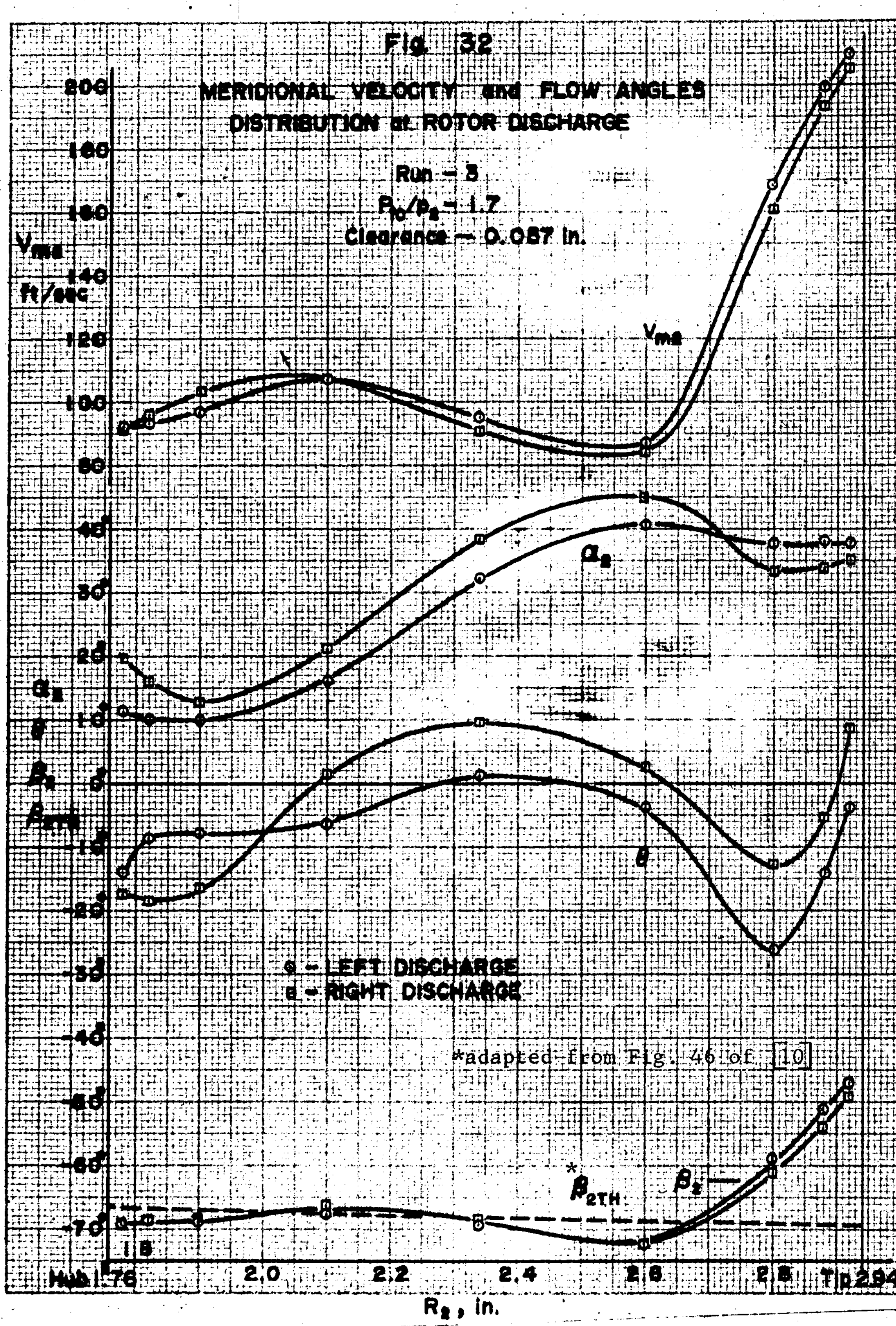


Fig. 32
MERIDIONAL VELOCITY and FLOW ANGLES
DISTRIBUTION at ROTOR DISCHARGE
Run — 3
Clearance — 0.057 in.
Vms
ft/sec
α2
β2
β2TH
○ – LEFT DISCHARGE
□ – RIGHT DISCHARGE
*adapted from Fig. 46 of [10]
Hub 1.76
2.0
2.2
2.4
2.6
2.8
Tip 2.94
R2, in.

8. Bibliography.

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APPENDIX A

PROGRAM SURVEY

A1. General

Program SURVEY was written to evaluate the rotor discharge survey data, obtained from the two United Sensor DA-120 pressure probes, with or without the data from the total temperature probes. The output of the program gives the flow properties at several discharge radii from the hub to the tip of the blade and the mass flow averaged data for each discharge as a whole. The program can process a maximum of 60 radial discharge points per discharge. A block diagram of the program is shown in Fig. A1 and a program listing is given in Table A1. All survey data are read into the program with those of the left discharge entered first.

The program initially reads the pressure probe calibration curve data of Figs. A2 and A3, the number of sets of data (NSETS) to be evaluated, and the number of survey points per discharge (NPTS). NPTS must be the same for both left and right discharges. The location of the survey points (NP) is read next. NP is an indexed input based on 60 points per discharge at 0.02 inch intervals for the radius R_2 varying from 1.76 inches at the hub to 2.94 inches at the tip. The points investigated have a value of NP(K) equal to unity whereas those points not investigated have a value of NP(K) equal to zero. The survey points do not have to correspond between the left and right discharges.

The calibration curve data is then printed out, followed by the reading and evaluation of each set of data.

Each set of data is indexed, the radial positions of the probes are calculated and indexed, and the non-survey data and the survey data with the appropriate radial positions are printed out. The indexing and calculation of the probe position is accomplished by a DO loop, varying the loop index J from 1 to 120. NP(J) is checked first. If it is equal to zero, J is increased one count and the next point is checked. If NP(J) is equal to unity, the survey pressure data for that point are transferred to the new indexed address and the radial position of the probe is computed from

$$R(J) = 1.76 + 0.02\ (J-1) \tag{A1}$$

Since indices 61 through 120 pertain to the right discharge, the index J is checked and if it is greater than 60, J is decreased by 61 instead of 1 in the calculation of R(J).

The data is processed in three sections within the program. The first section analyzes the data that is independent of the discharge survey whereas the second section analyzes data that is dependent on the discharge survey. The third section calculates the average values of several rotor parameters and handles the printing of the output. All three sections utilized several subroutines. The subroutines are described in sections A2 through A11. A description of the main program is given below.

In section I, the value of the specific gravity of mercury at room temperature t_{rm} is determined by

$$G_{Hg} = 13.638 - 1.354(10^{-3})\ t_{rm} \tag{A2}$$

The above relation was obtained from tabulated data found in [6] and holds for temperatures between 0^oF and 150^oF. The factor for converting in Hg to lb/ft^2 is

$$C_f = 69.892\ \frac{G_{Hg}}{13.59} \tag{A3}$$

Subroutines TEMP and FLOW are used in this section.

Section II processes the data for each radial discharge point for the left and right discharges using a DO loop. The loop index K varies from 1 to 120. Since not all 120 survey points need be used, NP(K) is checked in the same manner as used in the indexing process. Therefore, only the data for the survey points investigated are evaluated. The initial step in evaluating the survey data is the calculation of the actual dynamic discharge pressure $(P_{t2} - p_2)$ and the difference between the measured and actual total discharge pressures from the probe calibration curve data.

The yaw angle, α_1, was read directly from the protractor mounted on the probe holder after the static pressures p_2' and p_3' were equalized. The pitch angle θ is determined by the pitch angle coefficient PPCC or $(p_4' - p_5')/(P_1' - p_2')$. PPCC is compared with the probe calibration curve data to determine the data indices J and J+1 between which PPCC lies. If PPCC is less than zero, the values J, J+1 and J+2

are used to select the three calibration curve data values of the pitch angle coefficient PPC and pitch angle THET. With these values of PPC and THET, an analytical expression for a second order polynomial is calculated by subroutine DETERM. From this polynomial, the value of Θ corresponding to PPCC is computed. If PPCC is greater than zero, the indices of the calibration curve data are J-1, J and J+1.

The velocity pressure coefficient VPCC or $(P_{t2} - p_2)/(P_1' - p_2')$ is obtained from the calibration curve data for the velocity pressure coefficients VPC1 and VPC2. The values of VPC1 and VPC2 hold for a Mach number error factor M_r of 0.06 and 0.02, respectively, where

$$M_r = \frac{(P_1' - p_2')}{P_1' \text{ abs}} \tag{A4}$$

In general, the indicated static pressure p_2' increases linearly with M_r. Therefore, by computing M_r for the measured data for the discharge point under consideration, three intermediate values of VPCC are found by interpolation using a DO loop. The loop index varies from J to J+2. The interpolation equation is

$$\text{VPCX(I)} = \text{VPC2(I)} + \Big(\text{VPC1(I)} - \text{VPC2(I)}\Big)\left(\frac{M_r - 0.02}{0.04}\right) \tag{A5}$$

Using subroutine DETERM for the three values of VPCX and the corresponding values of THET, the coefficients of another second order polynomial are determined. From this polynomial, the value of VPCC corresponding to Θ is determined.

Since all values of the total pressure coefficient $(P_1' - P_{t2})/(P_{t2} - p_2)$ from the calibration curve data were zero, the actual value of the total pressure coefficient TPCC is set equal to zero.

The actual dynamic pressure is then

$$(P_{t2} - p_2) = \text{VPCC}\ (P_1' - p_2') \tag{A6}$$

Since TPCC is equal to zero, the measured and actual total pressures are equal $(P_1' = P_{t2})$.

Because of the flow pitch angle θ , and since the probes were located at a distance BP from the trailing edges of the blades, the actual radius at the discharge is computed from

$$R_2 = R(K) - BP \tan \theta \tag{A7}$$

The distance BP differs for the left and right discharges (see Fig. 5) and depends on the axial tip clearance of the rotor.

The subroutines PRESS, EDC, EFFIC and VEL are used in this section. If a temperature survey has been made, two additional subroutines, DISTEMP and DISVEL, are used. The temperature survey data is read into the program on data cards separate from those used for the pressure survey data. Therefore, blank cards must be inserted in the input data cards if no temperature survey was made.

In the last section (III) subroutine AVE is used to compute the mass averaged values of several of the discharge parameters.

The author wishes to acknowledge the use of the program SURVEY by Finn [3] which was the basis of the program SURVEY presented in this report.

A2. Subroutines TEMP and DISTEMP

Subroutine TEMP calculates the total temperature ahead of the flow measuring orifice and at the turbine inlet from chromel-alumel thermocouple readings. Subroutine DISTEMP calculates the total temperatures for the survey at the left and right rotor discharges from iron-constantan thermocouple readings. Using the measured voltage MV and the cold junction temperature t_{cj} the relations for the evaluation of the temperatures in TEMP are

for $t \leq 100^{\circ}F$

$$t = t_{cj} + 44.41\ MV + 0.2185\ MV^2 \qquad \text{(A8a)}$$

for $100^{\circ}F < t \leq 200^{\circ}F$

$$t = t_{cj} + 45.24\ MV - 0.3295\ MV^2 \qquad \text{(A8b)}$$

and in DISTEMP are

for $t \leq 100^{\circ}F$

$$t = t_{cj} + 36.53\ MV - 0.7638\ MV^2 \qquad \text{(A8c)}$$

for $100^{\circ}F < t \leq 200^{\circ}F$

$$t = t_{cj} + 35.60\ MV - 0.2812\ MV^2 \qquad \text{(A8d)}$$

The relations for both types of thermocouples were obtained from tabulated data in [7].

A3. Subroutine FLOW

Subroutine FLOW calculates the turbine flow rate using only the vena contracta tap data since this data gives a more accurate flow rate compared to the flange tap data.[1] The flow rate is measured with a sharp edge orifice of 2.800 inch diameter which is installed in a pipe of 4.026 inch I.D.

The relation for the flow rate is[2]

$$\dot{W}_{vc} = C \alpha Y_1 F_r \sqrt{\frac{p_{1vc} \Delta h_{vc}}{T_4}} \qquad \text{(A9)}$$

where:

- C - factor dependent on orifice diameter and type of pressure taps used
- α - area multiplier to account for the thermal expansion of the orifice
- Y_1 - expansion factor to account for compressibility effects
- F_r - Reynolds number correction factor
- p_{1vc} - absolute pressure at upstream tap
- Δh_{vc} - pressure differential across orifice
- T_4 - temperature ahead of the orifice

For a steel orifice[3]

-6

$$\alpha = 1 + (T_4 - 530)(10^{-3}) \qquad \text{(A10)}$$

[1]Vavra, M.H. Results of Turbine Air Testing Program, Phase II, Report ALGR No. 29, for Aerojet General Corporation (1965), p. 219.

[2]*Ibid.*, p. 220.

[3]*Ibid.*, p. 220.

and

$$Y_1 = 1 - 0.351 \frac{\Delta h_{vc}}{p_{1vc}} \qquad \text{(A11)}$$

For vena contracta taps[4], C = 0.9057 and

$$F_r = 1 + \frac{0.00114}{X} \qquad \text{(A12)}$$

For an orifice with a diameter of 2.800 inches[5]

$$X = 0.812 \frac{W_{vc}}{Z} \qquad \text{(A13)}$$

where for air between 50°F and 300°F

$$Z = 1.9 + 2.4(T_4 - 560)(10^{-3}) \qquad \text{(A14)}$$

Since F_r is nearly unity, the flow rate $\dot{W}_{vc}^*$ is determined first for $F_r = 1$. This flow rate is used to determine X using Eq. (A13), then the actual flow rate is taken as

$$\dot{W}_{vc} = F_r \dot{W}_{vc}^* \qquad \text{(A15)}$$

without further iteration.

p_{1vc} and Δh_{vc} are converted to the proper units from their respective measured values by the relations

$$p_{1vc} = (p_{1vc}' - \text{tare} + 2.54\ P_{atm}) \frac{G_{Hg}}{13.59} \qquad \text{(A16)}$$

and

$$\Delta h_{vc} = (\Delta h_{vc}' - \text{tare}) \frac{G_{Hg}}{13.59} \qquad \text{(A17)}$$

[4] Ibid., p. 221.

[5] Ibid., p. 220.

A4. Subroutine DETERM

Subroutine DETERM computes the coefficients of a second order polynomial for three points indexed by J, J+1 and J+2 by the Method of Determinants.

A5. Subroutine PRESS

Subroutine PRESS establishes the total and static discharge pressure, the total-to-static pressure ratio of the turbine and the ratio of the static pressures ahead of and after the rotor for different radii at the turbine discharge.

The total discharge pressure P_{t2} is determined from the differential pressures $(P_1' - P_{atm}')$ and $(P_1' - P_{t2})$ where

$$P_{t2} = \frac{(P_1' - P_{atm}') - (P_1' - P_{t2}) + P_{atm}G_{Hg}}{13.59} \tag{A18}$$

Using the results of Eqs. (A6) for $(P_{t2} - p_2)$, the static discharge pressure p_2 is then

$$p_2 = P_{t2} - \frac{(P_{t2} - p_2)}{13.59} \tag{A19}$$

From the measured static pressure p_5' at the turbine inlet, the absolute static pressure p_o at the turbine inlet is

$$p_o = \frac{p_5' - \text{tare}}{2.54} + P_{atm}\left(\frac{G_{Hg}}{13.59}\right) \tag{A20}$$

An iteration process is used to determine an average value of the total pressure at the turbine inlet. Three relations are used in the iteration, namely, the gas law,

$$\rho_o = C_f \frac{p_o}{R_g T_o} \tag{A21}$$

the continuity equation,

$$V_o = \frac{\dot{W}_{vc}}{\rho_o A_5} \tag{A22}$$

and the energy equation

$$T_o = T_{to} - \frac{V_o^{\ 2}}{2gJc_p} \tag{A23}$$

where A_5 is the area of the five-inch pipe and c_p is the specific heat of air at T_{to}. Using T_{to} for the first approximation of ρ_o, the iteration continues until a difference of 0.01^o or less exists between any two successive values of T_o. The total pressure P_{to} is then

$$P_{to} = p_o + \frac{V_o^{\ 2}}{2gC_f} \tag{A24}$$

The total to static pressure ratio of the turbine is P_{to}/p_2.

Using the measured pressure drop from the turbine inlet to the rotor inlet $(h_{16} - h_{20})$, the static pressure ahead of the rotor p_1 is

$$p_1 = p_o - (h_{16} - h_{20}) \frac{G_{Hg}}{13.59} \tag{A25}$$

The ratio of the static pressures ahead of and after the rotor is p_1/p_2.

A6. Subroutine EDC

Subroutine EDC establishes the mean values of γ and c_p for the arithmetic mean of total turbine inlet and static isentropic discharge temperatures for different radii at the turbine discharge.

The variations of γ and c_p with temperature, obtained from tabulated data in [4], are

$$\gamma = 1.4018 - 2(10^{-5})\ t \tag{A26}$$

$$c_p = 0.23943 + 3.4(10^{-6})\ t + 2(10^{-8})\ t^2 \tag{A27}$$

These values are valid from approximately 40^{o}F to 170^{o}F. γ_{av} and $c_{p(av)}$ correspond to the average temperature through the turbine based on isentropic conditions. The average temperature t is taken as

$$t = (T_{to} - 459.7) - \frac{\Delta T_{is}}{2} \tag{A28}$$

where

$$\Delta T_{is} = T_{to}\left[1 - \left(\frac{p_2}{P_{to}}\right)^{\frac{\gamma-1}{\gamma}}\right] \tag{A29}$$

Using an iteration process, the first approximation of ΔT_{is} is based on a value of γ corresponding to T_{to}. Further approximations use the value of γ for the previously evaluated temperature t until the difference between any two successive values of t is less than 0.1^{o}. Using the final value of t, the quantities γ_{av} and $c_{p(av)}$ are computed from Eqs. (A26) and (A27).

A7. Subroutine EFFIC

Subroutine EFFIC calculates the shaft horsepower, and the local isentropic horsepower and the efficiency for each discharge radii.

To calculate the shaft horsepower HP_s the torque T must be determined first. This is accomplished by subroutine DYNA. With torque T

$$HP_s = \frac{T \pi N}{198,000} \tag{A30}$$

The local isentropic horsepower HP_{is} is the power which the turbine could generate for an isentropic expansion from P_{to} to p_2 or

$$HP_{is} = \frac{W_{vc} c_p J \Delta T_{is}}{550} \tag{A31}$$

and the efficiency based on the local isentropic horsepower becomes

$$\eta_{is} = \frac{HP_s}{HP_{is}} \tag{A32}$$

η_{is} is not equal to the overall efficiency. The overall efficiency is determined by a mass flow weighted average of all the values of η_{is}. The local efficiency η_L is determined later by subroutine VEL.

A8. Subroutine DYNA

Subroutine DYNA determines the torque from the dynamometer calibration data obtained prior to each run. The data is tabulated in Table A2 for all runs.

The values of the torque indicator reading from the calibration data TCD(J) are read into the program by means of a one-dimensional array beginning with the zero load value for TCD(1). These values of TCD(J) are for torque intervals of 100 in-lbs. Using a DO loop with index J, the torque indicator reading TQ is compared with the values of

TCD(J) to determine the indices J and J+1 between which TQ lies. Since the calibration curve data is very nearly linear, a straight line approximation between TCD(J) and TCD(J-1) is used to compute the torque, or

$$T = 100(J-1) + 100\left(\frac{TQ - TCD(J)}{TCD(J+1) - TCD(J)}\right) \tag{A33}$$

A9. Subroutine VEL

Subroutine VEL determines the degree of reaction, the rotor inlet parameters and for different discharge radii, the rotor discharge parameters.

The thermodynamic process of a fluid passing through the turbine can be seen in Fig. 18. The velocity diagram for the turbine is shown in Fig. 19. A majority of the relations in this subroutine were derived using these diagrams.

The degree of reaction r* is obtained from

$$(1 - r^*)\Delta T_{is} = T_{to}\left[1 - \left(\frac{p_1}{P_{to}}\right)^{\frac{\gamma-1}{\gamma}}\right] \tag{A34}$$

or

$$r^* = 1 - \frac{T_{to}}{\Delta T_{is}}\left[1 - \left(\frac{p_1}{P_{to}}\right)^{\frac{\gamma-1}{\gamma}}\right] \tag{A35}$$

The velocity coefficient φ, defined as

$$\varphi = \frac{V_1}{V_{1th}} \tag{A36}$$

and the absolute rotor inlet flow angle α_1 were found to be

0.889 and 80.0 degrees, respectively, by program SCROLL. With φ and α_1, the conditions at the rotor inlet can be obtained.

Using the quantity expressed by Eq. (A34) and φ, the absolute velocity V_1 and the static temperature T_1 are given by

$$V_1 = \varphi\sqrt{2gJc_p(1 - r^*)\Delta T_{is}} \quad \text{(A37)}$$

and

$$T_1 = T_{to} - \varphi^2(1 - r^*)\Delta T_{is} \quad \text{(A38)}$$

The peripheral and meridional components of V_1 are then

$$V_{u1} = V_1 \sin \alpha_1 \quad \text{(A39)}$$

and

$$V_{m1} = V_1 \cos \alpha_1 \quad \text{(A40)}$$

respectively. For a rotor radius of 4.7 inches, the peripheral velocity of the rotor at the inlet is

$$U_1 = \frac{4.7\pi N}{360} \quad \text{(A41)}$$

where N is the rotor speed. Therefore, the peripheral component of the relative rotor inlet velocity W_1 is

$$W_{u1} = V_{u1} - U_1 \quad \text{(A42)}$$

W_1 is then

$$W_1 = \sqrt{V_{m1}^2 + W_{u1}^2} \quad \text{(A43)}$$

To determine the theoretical relative velocity W_{2th} at the rotor discharge, it is necessary to determine first the temperature at state points E and 2'. The equivalent state point E represents the total conditions that would exist at the rotor inlet if the rotor were considered as a stationary passage with a static discharge pressure p_2. The temperature at state point E is

$$T_E = T_1 + \frac{(W_1^2 - U_1^2 + U_2^2)}{2gJc_p} \tag{A44}$$

where the peripheral velocity U_2 at the rotor discharge is

$$U_2 = \frac{R_2 \pi N}{360} \tag{A45}$$

To account for non-uniform flow conditions at the rotor inlet and for possible flow separations at the rotor blades due to the incidence angle of flow approaching the rotor, the carry-over coefficient Φ_i is introduced. Assuming that the useful kinetic energy at the rotor inlet is $\Phi_i W_1^2/2gJc_p$ and that $\Phi_i = V_{m1}^2/W_1^2$ [11], the effective static temperature at the rotor inlet is

$$T_1' = T_1 + (1 - \Phi_i) \frac{W_1^2}{2gJc_p} \tag{A46}$$

Therefore, the static temperature at state point 2' is

$$T_2' = T_1' \left(\frac{p_2}{p_1}\right)^{\frac{\gamma - 1}{\gamma}} \tag{A47}$$

W_{2th} is then

$$W_{2th} = \sqrt{2gJc_p\,(T_E - T_2')} \tag{A48}$$

For this subroutine, it is assumed that the total discharge temperature T_{t2} is not known. To determine T_{t2} an iteration process is used. The first approximation of T_{t2} is based on the assumption that the efficiency is constant in the radial direction, or

$$T_{t2} = T_{to} - \eta_{is}\Delta T_{is} \tag{A49}$$

A second approximation of T_{t2} is obtained using the first approximation of T_{to}. By combining and rearranging Eqs. (A50) through (A52)

$$T_2 = T_{t2} - \frac{V_2^{\,2}}{2gJc_p} \tag{A50}$$

$$\rho_2 = C_f\,\frac{p_2}{R_g T_2} \tag{A51}$$

$$V_2 = \sqrt{\frac{2(P_{t2} - p_2)}{\rho_2}} \tag{A52}$$

there is obtained a value for the absolute rotor discharge velocity V_2, or

$$V_2 = \sqrt{\frac{2gR_g(P_{t2} - p_2)\,T_{t2}}{p_2 + \frac{R_g}{Jc_p}\,(P_{t2} - p_2)}} \tag{A53}$$

The peripheral component of V_2 is then

$$V_{u2} = V_2 \sin \alpha_2 \tag{A54}$$

With Euler's turbine equation[6], the work output is

$$\Delta H_w = \frac{U_1 V_{u1} - U_2 V_{u2}}{gJ} \tag{A55}$$

Hence, there is obtained a second approximation for T_{t2}, where

$$T_{t2} = T_{to} - \frac{\Delta H_w}{c_p} \tag{A56}$$

By increasing or decreasing η_{is} until the two values for T_{t2} agree within 0.05°, the local efficiency η_L and the discharge velocity V_2 in addition to T_{t2} are determined.

The relative discharge velocity is

$$W_2 = \sqrt{V_{m2}^2 + W_{u2}^2} \tag{A57}$$

where V_{m2} and W_{u2} are expressed by Eqs. (A58) and (A59).

$$V_{m2} = V_2 \cos \alpha_2 \tag{A58}$$

$$W_{u2} = V_{u2} - U_2 \tag{A59}$$

The relative discharge flow angle β_2 is then

$$\beta_2 = \tan^{-1} \frac{W_{u2}}{V_{m2}} \tag{A60}$$

[6]Vavra, M. H. Aero-Thermodynamics and Flow in Turbomachines (John Wiley and Sons, 1960), p. 425.

The rotor loss coefficient, which is a measure of the kinetic energy loss through the rotor, is

$$\zeta_R = 1 - \Psi^2 \tag{A61}$$

where the velocity coefficient Ψ is defined as

$$\Psi = \frac{W_2}{W_{2th}} \tag{A62}$$

With high rotational speeds and small discharge radii, it is possible that T_E may be less than T_2', implying that W_{2th}^2 is negative. Theoretically, at least, this condition indicates that there will be no flow passing through the annulus formed by this radial position and the hub radius. A check for this condition is made and if it exists, W_{2th}, W_2, and Ψ are set equal to zero.

For later use in computing average discharge parameters, the axial component of V_{u2} is also determined, where

$$V_{a2} = V_{u2} \cos \Theta \tag{A63}$$

A10. Subroutine DISVEL

Subroutine DISVEL determines the rotor discharge parameters for the different discharge radii, and the local values of the rotor inlet parameters and velocity coefficient φ from the rotor discharge pressure and temperature surveys.

The absolute rotor velocity V_2, the relative rotor velocity W_2, the relative flow angle β_2 and the static temperature T_2 at the rotor discharge are determined from

Eqs. (A53), (A57), (A60) and (A50), respectively. The equivalent temperature T_E is given by Eq. (A44).

The local value of φ and the inlet parameters are obtained by iteration. A first approximation of the relative rotor inlet velocity W_1 is obtained using Eq. (A37) where φ is initially set equal to unity and Eqs. (A64) through (A66). A second approximation of W_1 is obtained using Eqs. (A39) through (A43) and V_1 as determined by Eq. (A37) in the first approximation. φ is reduced in steps of 0.0001 until the two approximations for W_1 agree within 1.0 ft/sec. The iteration uses the value of α_1 determined by program SCROLL.

The theoretical relative discharge velocity W_{2th} is determined using Eqs. (A46) through (A48). As in subroutine VEL, W_{2th}, W_2 and φ are set equal to zero if T_E is less than T_2'.

The local efficiency is

$$\eta_L = 100 \frac{T_{to} - T_{t2}}{\Delta T_{1s}} \tag{A64}$$

For later use in subroutine AVE, the axial component of the peripheral component of V_2 is computed using Eq. (A63).

A11. Subroutine AVE

Subroutine AVE is used to obtain the mass averaged values of several of the rotor discharge parameters. It is an integrating routine using the trapizodial rule.

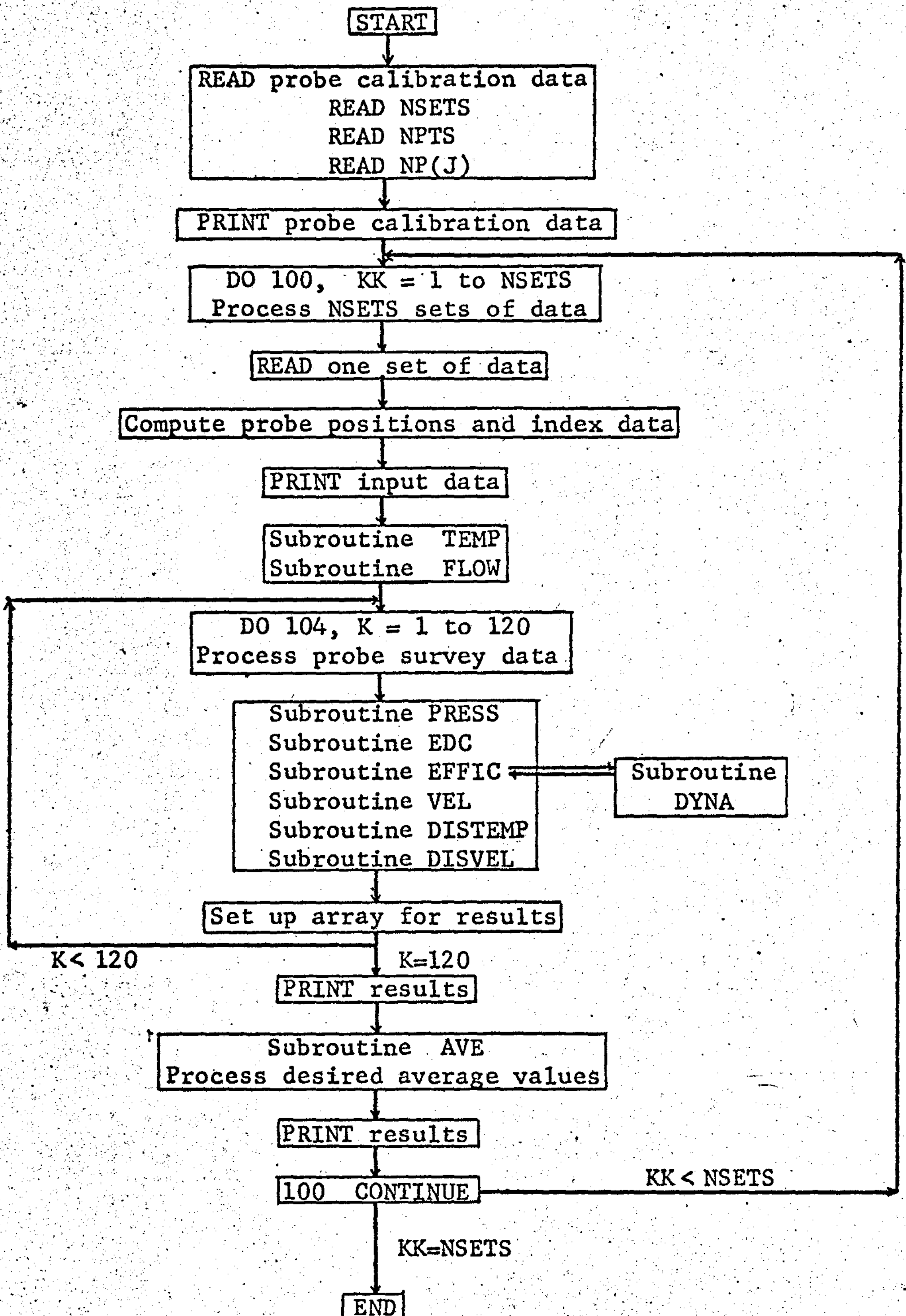

Fig. A1

Block Diagram of Program SURVEY

TABLE A1

LISTING FOR PROGRAM SURVEY

```
••JOB0571F,RILEY
      PROGRAM SURVEY
      DIMENSION PPCT(66),THETT(66),VPC1T(66),VPC2T(66),TPCT(66),NP(120),
     1H1AT(120),HATMT(120),H1BT(120),H2T(120),H5T(120),H4T(120),ALF2T(12
     20),VT2T(120),B1P(120) ,ECC(120),TCD(5),R2P(120),R2T(60),
     3PPC(33),THET(33),VPC1(33),VPC2(33),VPCX(33),TPC(33),H1A(120),HATM(
     4120),H1B(120),H4(120),H5(120),ALF2(120),VT2(120),R(120),H2(120),
     5PINP(120),PIRP(120),P2P(120),DRP(120),V1P(120),V2P(120),VA2P(120),
     6W2P(120),W2THP(120),T1P(120),THEP(120),T2PP(120),TTAP(120),TPP(120
     7),B2P(120),EVCP(120),PSIP(120),ZETAP(120),D(120),PT(60),V1PP(120),
     8V2PP(120),VAP(120),W2PP(120),W2TPP(120),T1PP(120),          T22P(1
     920),TT2P(120),TS2(120),ETAP(120),PSIPP(120),ZETPP(120),PH(120)
      COMMON  LL,K,GHG,CF1,T4,T5,WVC,TARE,PATM,PT2,PS2,PIN,PIR,EXP,DT,
     1CP,RPM,U1,EVCC,R2,DPTS2,U2
C
C COMMENT 1 -- READ IN DATA.  NUMBER OF CARDS ---- NSETS - 1, NPTS - 1,
C               NP - 2, READ 12 - 66, READ 13 - NPTS, READ 14 - 1 AND
C               READ 15 - 1.
C
      READ 10,(PPCT(I),THETT(I),VPC1T(I),VPC2T(I),TPCT(I),I=1,66)
      READ 11,NSETS
      READ 11,NPTS
      READ 12,(NP(J),J=1,120)
      PRINT 19
      PRINT 21
      PRINT 22,(I,PPCT(I),THETT(I),VPC1T(I),VPC2T(I),TPCT(I),I=1,66)
      DO 100 KK =1,NSETS
      READ 13,(H1AT(I),HATMT(I),H1BT(I),H2T(I),H4T(I),H5T(I),ALF2T(I),I=
     11,NPTS)
      READ 14,TARE,PUVC,P5P,DPVC,RPM,TQ,TCJ,V4,V5,PATM
```

```
      READ 15,TRM,H19,H20,H16,CMR1,CMR2,CL,PR,BPL,BPR,NRUN
      READ 16,(TCD(I),I=1,5)
      READ 17,(VT2T(I),I=1,NPTS)
C
C COMMENT 2 -- INDEX PRESSURE PROBE READINGS, COMPUTE RADII AND PRINT
C             OUT INPUT DATA.
C
      PRINT 20,NRUN,CL,PR
      PRINT 23,RPM,TARE,PUVC,DPVC,H16,H19,H20,P5P,PATM,TRM,V4,V5,TCJ,TQ
      PRINT 24
      PRINT 25
      I = 1
      DO 101 J=1,120
      IF(NP(J))101,101,102
  102 H1A(J)=H1AT(I)
      HATM(J)=HATMT(I)
      H1B(J)=H1BT(I)
      H2(J)=H2T(I)
      H4(J)=H4T(I)
      H5(J)=H5T(I)
      ALF2(J)=ALF2T(I)
      VT2(J) = VT2T(I)
      I=I+1
      IF(J-60)103,103,2000
  103 AK=J
      GO TO 2001
 2000 AK=J-60
 2001 R(J)=1.76+(AK-1.)*.02
      PRINT 26,  R(J),H1A(J),HATM(J),H1B(J),H2(J),H4(J),H5(J),ALF2(J)
     1,VT2(J)
  101 CONTINUE
C
C
C--------------    SECTION I-       ----------
C
C
```

```
      GHG = 13.638 - 1.354E-3*TRM
      CF1=69.892*GHG/13.59
      GOL=.834
C
C COMMENT 3 -- CALCULATE TEMPERATURE AT MASS FLOW ORIFICE (T4) AND AT
C             TURBINE CASING INLET (T5).
C
      CALL TEMP (TCJ,V4,V5)
C
C COMMENT 4 -- CALCULATE MASS FLOW RATE (WVC).
C
      CALL FLOW(DPVC,PUVC)
C
C
C---------------     SECTION II       ----------
C
C
      LL=1
      DO 104 K=1,120
      IF(NP(K))104,104,105
  105 IF (K-60)107,107,106
  106 H20=H19
      DO 2005 I=1,33
      PPC(I)=PPCT(I+33)
      THET(I)=THETT(I+33)
      VPC1(I)=VPC1T(I+33)
      VPC2(I)=VPC2T(I+33)
      TPC(I)=TPCT(I+33)
 2005 CONTINUE
      GO TO 108
  107 DO 2006 I=1,33
      PPC(I)=PPCT(I)
      THET(I)=THETT(I)
      VPC1(I)=VPC1T(I)
      VPC2(I)=VPC2T(I)
      TPC(I)=TPCT(I)
```

```
 2006 CONTINUE
C
C COMMENT 5 -- CALCULATE ACTUAL TOTAL AND STATIC DISCHARGE PRESSURES
C              (PT2 AND PS2) FROM SURVEY READINGS WITH 3-D PROBES.
C
  108 DP1A=-(H1A(K)-HATM(K))*GOL/2.54
      DP12=-(H1B(K)-H2(K))*GOL/2.54
      DP45=-(H4(K)-H5(K))*GOL/2.54
      PPCC=DP45/DP12
      IF(PPCC) 109,115,116
  109 IF(PPCC-PPC(1))110,111,113
  110 PRINT 2040,K,PPCC,PPC(1)
 2040 FORMAT(1H1,4HERR1,I4,2F8.3)
  111 J=1
  112 THETA=THET(J)
      GO TO 121
  113 DO 2007 J=2,17
      IF(PPCC-PPC(J))114,112,2007
  114 J=J-1
      GO TO 120
 2007 CONTINUE
  115 J=17
      THETA=THET(J)
      GO TO 121
  116 IF(PPCC-PPC(33))118,117,99
   99 PRINT 2041,K,PPCC,PPC(33)
 2041 FORMAT(1H1,4HERR1,I4,2F8.3)
  117 J=33
      THETA=THET(J)
      GO TO 121
  118 DO 2008 J=18,33
      IF(PPC(J)-PPCC)2008,112,119
  119 J=J-1
      GO TO 120
 2008 CONTINUE
  120 JJ=J
```

```
      CALL DETERM(THET,PPC,A,B,C,JJ)
      THETA=A+B*PPCC+C*PPCC**2
  121 CM=DP12/(DP1A+PATM*GHG)
      JJ=J
      DY=CM-CMR2
      DIF=CMR1-CMR2
      JP2=J+2
      DO 123 I=J,JP2
      VPCX(I)=VPC2(I)+(VPC1(I)-VPC2(I))*DY/DIF
  123 CONTINUE
      CALL DETERM(VPCX,THET,A3,B3,C3,JJ)
      VPCC=A3+B3*THETA+C3*THETA**2
      TPCC=0.0
      DPTS2=VPCC*DP12
      DP1T2=TPCC*DPTS2
      IF(K-60)136,136,137
  136 BP=BPL
      GO TO 138
  137 BP=BPR
  138 R2=R(K)-BP*TANF(THETA/57.29578)
      R2P(K)=R(K)
C
C COMMENT 6 -- CALCULATE PT2 PS2, PTO, PIN, AND PIR.
C
      CALL PRESS (P5P,H16,H20,DP1A,DP1T2)
C
C COMMENT 7 -- CALCULATE AVERAGE EXP, CP, AND DT.
C
      CALL EDC
C
C COMMENT 8 -- CALCULATE SHAFT HP, LOCAL ISENTROPIC HP AND THE EVCC.
C
      CALL EFFIC (TQ,TCD)
      ALP2=ALF2(K)
      ECC(K)=EVCC
C
```

```
C COMMENT 9 -- CALCULATE VELOCITIES (V1, W1, U1, U2, V2, W2, W2TH), BETA
C               2, DEGREE OF REACTION (DR), DISCHARGE TEMPERATURES AND
C               VALUES FOR PSI AND ZETA.
C
      CALL VEL (ALP2,DR,V1,V2,W1,W2,W2TH,T1,B1 ,T2P,T2 ,PHII,B2,VA2,TT2
     1,PSI,ZETA,THETA)
      PINP(K)=PIN
      PIRP(K)=PIR
      P2P(K)=PS2
      DRP(K)=DR
      V1P(K)=V1
      V2P(K)=V2
      VA2P(K)=VA2
      W2P(K)=W2
      W2THP(K)=W2TH
      T1P(K)=T1
      T2PP(K)=T2P
      TTAP(K)=TT2
      TPP(K)=T2
      B1P(K)=B1
      B2P(K)=B2
      THEP(K)=THETA
      EVCP(K)=EVCC
      PSIP(K)=PSI
      ZETAP(K)=ZETA
      D(K)=1.
      IF(VT2(K))104,104,128
  128 VD=VT2(K)
C
C COMMENT 10 -- CALCULATE DISCHARGE TEMPERATURES FROM PROBE SURVEY.
C
      CALL DISTEMP (VD,TCJ,TT2)
C
C COMMENT 11 -- CALCULATE DISCHARGE VELOCITIES AND STATIC TEMPERATURES
C                BASED UPON TEMPERATURE SURVEY.  DETERMINE NEW VALUES FOR
C                PSI AND ZETA.
```

```
C
      CALL DISVEL (TT2,ALP2,THETA,VA2,V1,V2,W2,W2TH,T1,T2,TTE,T2P,B2,
     2ETA,PSI,ZETA,PHI)
      V1PP(K)=V1
      V2PP(K)=V2
      VAP(K)=VA2
      W2PP(K) = W2
      W2TPP(K)=W2TH
      T1PP(K)=T1
      T22P(K)=T2P
      TT2P(K) = TT2
      TS2(K) = T2
      ETAP(K)= ETA
      PSIPP(K) = PSI
      ZETPP(K) = ZETA
      PH(K)=PHI
  104 CONTINUE
C
C
C-------------------SECTION III-------------------
C
C
      PRINT 27,NRUN,CL,RPM
      DO 129 K = 1,120
      IF(NP(K))129,129,130
  130 PRINT 28,R(K),PINP(K),PIRP(K),DRP(K),V1P(K),V2P(K),W2P(K),W2THP(K)
     1,PSIP(K),ZETAP(K),T1P(K),TPP(K),T2PP(K),B1P(K),B2P(K),THEP(K),EVCP
     2(K)
  129 CONTINUE
C
C COMMENT 12 -- CALCULATE MASS AVERAGED VALUES OF W2, W2TH, TT2, AND
C               MASS FLOW AND DETERMINE AVERAGE VALUES OF PSI, ZETA AND
C               EFFICIENCY.
C
      CALL AVE (R2P,VA2P,P2P,TPP,D,W2P,NP,NPTS,CF1,WX)
      CALL AVE (R2P,VA2P,P2P,TPP,D,W2THP,NP,NPTS,CF1,WTX)
```

```
      CALL AVE (R2P,VA2P,P2P,TPP,ECC,D,NP,NPTS,CF1,EL)
      CALL AVE (R2P,VA2P,P2P,TPP,TTAP,D,NP,NPTS,CF1,TL)
      CALL AVE (R2P,VA2P,P2P,TPP,D,D,NP,NPTS,CF1,WDL)
      WAL=SQRTF(WX/WDL)
      WTAL=SQRTF(WTX/WDL)
      PAL = WAL /WTAL
      ZAL = 1.-PAL**2
      WL=2.*3.14159*WDL
      TAL=TL/WDL
      EVCL=EL/WDL
      ETAL=(T5-TAL)*100./DT
      DO 131 K=1,60
      R2T(K)=R2P(K+60)
      VA2P(K)=VA2P(K+60)
      PT(K)=P2P(K+60)
      TPP(K)=TPP(K+60)
      W2P(K)=W2P(K+60)
      W2THP(K)=W2THP(K+60)
      TTAP(K)=TTAP(K+60)
      ECC(K)=ECC(K+60)
  131 CONTINUE
      CALL AVE (R2T,VA2P,PT,TPP,D,W2P,NP,NPTS,CF1,WX)
      CALL AVE (R2T,VA2P,PT,TPP,D,W2THP,NP,NPTS,CF1,WTX)
      CALL AVE (R2T,VA2P,PT,TPP,TTAP,D,NP,NPTS,CF1,TR)
      CALL AVE (R2T,VA2P,PT,TPP,ECC,D,NP,NPTS,CF1,ER)
      CALL AVE (R2T,VA2P,PT,TPP,D,D,NP,NPTS,CF1,WDR)
      WAR=SQRTF(WX/WDR)
      WTAR=SQRTF(WTX/WDR)
      PAR=WAR/WTAR
      ZAR=1.-PAR**2
      WR=2.*3.14159*WDR
      TAR=TR/WDR
      EVCR=ER/WDR
      ETAR=(T5-TAR)*100./DT
      PRINT 31,WVC
      PRINT 32
```

```
      PRINT 33,WAL,WTAL,PAL,ZAL,WL,EVCL,ETAL,WAR,WTAR,PAR,ZAR,WR,EVCR,
     1ETAR
      IF(VT2T(1))100,100,132
  132 PRINT 34,NRUN,CL,RPM
      DO 133 K=1,120
      IF(NP(K))133,133,134
  134 PRINT 36,R(K),V1PP(K),V2PP(K),W2PP(K),W2TPP(K),PSIPP(K),ZETPP(K),T
     11PP(K),TS2(K),T22P(K),ETAP(K),PH(K)
  133 CONTINUE
      CALL AVE (R2P,VAP,P2P,TS2,D,W2PP,NP,NPTS,CF1,WX)
      CALL AVE (R2P,VAP,P2P,TS2,D,W2TPP,NP,NPTS,CF1,WTX)
      CALL AVE (R2P,VAP,P2P,TS2,TT2P,D,NP,NPTS,CF1,TL)
      CALL AVE (R2P,VAP,P2P,TS2,D,D,NP,NPTS,CF1,WDL)
      WAL=SQRTF(WX/WDL)
      WTAL=SQRTF(WTX/WDL)
      PAL=WAL/WTAL
      ZAL=1.-PAL**2
      WL=2.*3.14159*WDL
      TAL=TL/WDL
      ETAL=(T5-TAL)*100./DT
      DO 135 K=1,60
      VAP(K)=VAP(K+60)
      TS2(K)=TS2(K+60)
      TT2P(K)=TT2P(K+60)
      W2PP(K)=W2PP(K+60)
      W2TPP(K)=W2TPP(K+60)
  135 CONTINUE
      CALL AVE (R2T,VAP,PT,TS2,D,W2PP,NP,NPTS,CF1,WX)
      CALL AVE (R2T,VAP,PT,TS2,D,W2TPP,NP,NPTS,CF1,WTX)
      CALL AVE (R2T,VAP,PT,TS2,TT2P,D,NP,NPTS,CF1,TR)
      CALL AVE (R2T,VAP,PT,TS2,D,D,NP,NPTS,CF1,WDR)
      WAR=SQRTF(WX/WDR)
      WTAR=SQRTF(WTX/WDR)
      PAR=WAR/WTAR
      ZAR=1.-PAR**2
      WR=2.*3.14159*WDR
```

```
      TAR=TR/WDR
      ETAR=(T5-TAR)*100./DT
      PRINT 31,WVC
      PRINT 29
      PRINT 35,WAL,WTAL,PAL,ZAL,WL,EVCL,ETAL,WAR,WTAR,PAR,ZAR,WR,EVCR,
     1ETAR
  100 CONTINUE
      PRINT 37
   10 FORMAT(5F8.3)
   11 FORMAT(I4)
   12 FORMAT(60I1/60I1)
   13 FORMAT(7F7.2)
   14 FORMAT(4F7.2,F7.0,5F7.2)
   15 FORMAT(6F7.2,F7.3,F7.2,2F7.3,I7)
   16 FORMAT(5F7.1)
   17 FORMAT(20F4.2)
   19 FORMAT(1H1//3X14HPROGRAM SURVEY50X10HM.W. RILEY///24X31HAIR TESTS
     1OF ICP RADIAL TURBINE//21X38HTABLE           PROBE CALIBRATION DAT
     2A//)
   20 FORMAT(1H1/1X14HPROGRAM SURVEY66X10HM.W. RILEY///31X31HAIR TESTS O
     1F ICP RADIAL TURBINE//33X26HTABLE        MEASURED DATA//20X4HRUN I
     22,5X12HCLEARANCE - F4.3,5X17HPRESSURE RATIO - F4.2//1X89H  RPM   T
     3ARE  PUVC   DPVC   H16    H19    H20    P5P    PATM   TRM   V4
     4V5    TCJ   TQ/)
   21 FORMAT(19X44H I   PPC(I) THET(I)  VPC1(I) VPC2(I)  TPC(I)//)
   22 FORMAT(18X,I3,5F8.3)
   23 FORMAT(F7.0,F5.2,7F7.2,F6.1,2F6.2,2F6.1)
   24 FORMAT(///38X17HPROBE SURVEY DATA/)
   25 FORMAT(20X52H R2    H1A  HATM   H1B   H2    H4    H5   ALF2   VT2/
     1)
   26 FORMAT(19X,F5.2,7F6.1,F6.2)
   27 FORMAT(1H1/1X14HPROGRAM SURVEY94X10HM.W. RILEY///44X31HAIR TESTS O
     1F ICP RADIAL TURBINE//27X66HTABLE         OUTPUT DATA OBTAINED USI
     2NG DISCHARGE PRESSURE SURVEY/44X39HAND ITERATION FOR DISCHARGE TEM
     3PERATURE//38X4HRUN I2,5X12HCLEARANCE - F4.3,5X6HRPM - F6.0// 119H
     4 R2  PTO/P2  PI/P2   DR     V1      V2      W2    W2TH     PSI  ZETA(
```

```
     5R)  T1      T2     T2P    BETA1    BETA2    THETA ETA(L)/)
  28 FORMAT(F5.2,2F7.3,F6.3,4F7.1,2F7.3,3F7.1,3F8.2,F6.1)
  29 FORMAT( //37X30HMASS FLOW RATE AVERAGED OUTPUT//20X78H  W2
    1 W2TH            PSI          ZETA       MASS FLOW     ETA(HP)        ETA(T)
    2/)
  31 FORMAT(//38X35HMASS FLOW RATE (VENA CONTRACTA) -- F8.3)
  32 FORMAT( //44X30HMASS FLOW RATE AVERAGED OUTPUT//28X78H  W2
    1 W2TH            PSI          ZETA       MASS FLOW     ETA(HP)        ETA(T)
    2/)
  33 FORMAT(9X9HLEFT SIDE3X2F12.1,3F12.3,2F12.1/9X10HRIGHT SIDE2X2F12.1
    1,3F12.3,2F12.1)
  34 FORMAT(1H1/1X14HPROGRAM SURVEY74X10HM.W. RILEY///34X31HAIR TESTS O
    1F ICP RADIAL TURBINE//18X63HTABLE         OUTPUT DATA OBTAINED USI
    2NG DISCHARGE PRESSURE AND/35X18HTEMPERATURE SURVEY//28X4HRUN I2,5X
    312HCLEARANCE - F4.3,5X6HRPM - F6.0//11X78HR2       V1       V2      W2
    4   W2TH    PSI   ZETA(R)    T1      T2     T2P   ETA(L)   PHI/)
  35 FORMAT(1X9HLEFT SIDE4X2F12.1,3F12.3,2F12.1/1X10HRIGHT SIDE3X2F12.1
    1,3F12.3,2F12.1)
  36 FORMAT(6X,F8.2,4F7.1,2F7.3,3F7.1,F6.1,F6.3)
  37 FORMAT(1H1)
     END
C
     SUBROUTINE TEMP(TCJ,V4,V5)
     COMMON  LL,K,GHG,CF1,T4,T5,WVC,TARE,PATM,PT2,PS2,PIN,PIR,EXP,DT,
    1CP,RPM,U1,EVCC,R2,DPTS2,U2
     V=V4
     J=1
 100 T = TCJ + 44.41 * V + .2185 * V ** 2
     IF( T - 100.) 102,102,101
 101 T = TCJ + 45.24 * V - .3295 * V ** 2
 102 T=T+459.7
     IF(J-1)103,103,104
 103 J=2
     T4=T
     V=V5
     GO TO 100
```

```
  104 T5=T
      RETURN
      END
C
      SUBROUTINE FLOW (DPVC,PUVC)
      COMMON  LL,K,GHG,CF1,T4,T5,WVC,TARE,PATM,PT2,PS2,PIN,PIR,EXP,DT,
     1CP,RPM,U1,EVCC,R2,DPTS2,U2
      DVC=(DPVC-TARE)*GHG/13.59
      PVC=(PUVC-TARE+PATM*2.54)*GHG/13.59
      A=1.+1.E-5*(T4-530.)
      Z=1.9+2.4E-3*(T4-560.)
      Y=1.-.351*DVC/PVC
      IF(PVC*DVC/T4) 2070,2071,2071
 2070 PRINT 2072, K,PVC,DVC,T4
 2072 FORMAT (4HERR3, I4,3F8.3)
 2071 CONTINUE
      WVC=.9057*A*Y*SQRTF(PVC*DVC/T4)
      X=WVC*.812/Z
      WVC=(1.+.00114/X)*WVC
      RETURN
      END
C
      SUBROUTINE DETERM (X,Y,C1,C2,C3,K)
      DIMENSION X(40),Y(40)
      DET=Y(K+1)*(Y(K+2)**2)+Y(K)*(Y(K+1)**2)+(Y(K)**2)*Y(K+2)-Y(K+2)*(
     1Y(K+1)**2)-Y(K)*(Y(K+2)**2)-(Y(K)**2)*Y(K+1)
      C1=(X(K)*Y(K+1)*(Y(K+2)**2)+Y(K)*(Y(K+1)**2)*X(K+2)+(Y(K)**2)*Y(K+
     12)*X(K+1)-X(K)*Y(K+2)*(Y(K+1)**2)-Y(K)*X(K+1)*(Y(K+2)**2)-(Y(K)**2
     2)*Y(K+1)*X(K+2))/DET
      C2=(X(K+1)*(Y(K+2)**2)+X(K)*(Y(K+1)**2)+(Y(K)**2)*X(K+2)-X(K+2)*(Y
     1(K+1)**2)-X(K)*(Y(K+2)**2)-(Y(K)**2)*X(K+1))/DET
      C3=(Y(K+1)*X(K+2)+Y(K)*X(K+1)+X(K)*Y(K+2)-Y(K+2)*X(K+1)-Y(K)*X(K+2
     1)-X(K)*Y(K+1))/DET
      RETURN
      END
C
```

```
      SUBROUTINE PRESS(P5P,H16,H20,DP1A,DP1T2)
      COMMON  LL,K,GHG,CF1,T4,T5,WVC,TARE,PATM,PT2,PS2,PIN,PIR,EXP,DT,
     1CP,RPM,U1,EVCC,R2,DPTS2,U2
      PT2=(PATM*GHG/13.59)+(DP1A-DP1T2)/13.59
      PS2=PT2-DPTS2/13.59
      GO TO (902,903),LL
  902 A=T5-459.7
      CP=.23943+3.4E-6*A+2.E-8*A**2
      TT=T5
      PS5=(PATM+(P5P-TARE)/2.54)*GHG/13.59
C
C ITERATION TO DETERMINE PTO
C
  100 RHO=PS5*CF1/(TT*53.35)
      VO =WVC/(RHO*3.14159*6.25/144.)
      TO=T5-(VO **2)/(2.*32.174*778.16*CP)
      DTT=TT-TO
      TT=TO
      IF(ABSF(DTT)-.01)101,101,100
  101 PTO=PS5+RHO*(VO**2)/(2.*32.174*CF1)
  903 PIN=PTO/PS2
      PIR=(PS5-(H16-H20)*GHG/13.59)/PS2
      RETURN
      END
C
      SUBROUTINE EDC
      COMMON  LL,K,GHG,CF1,T4,T5,WVC,TARE,PATM,PT2,PS2,PIN,PIR,EXP,DT,
     1CP,RPM,U1,EVCC,R2,DPTS2,U2
      A=T5-459.7
C
C ITERATION TO DETERMINE GAMMA(AVE) AND CP(AVE)
C
  100 GAM = 1.4018-2.E-5*A
      EXP=(GAM-1.)/GAM
      DT=T5*(1.-1./PIN**EXP)
      AA=T5-459.7-DT/2.
```

```
      AAA=ABSF(AA-A)
      IF(AAA-.1)102,102,101
  101 A=AA
      GO TO 100
  102 CP=.23943+3.4E-6*AA+2.E-8*AA**2
      RETURN
       END
C
      SUBROUTINE EFFIC (TQ,TCD)
      COMMON  LL,K,GHG,CF1,T4,T5,WVC,TARE,PATM,PT2,PS2,PIN,PIR,EXP,DT,
     1CP,RPM,U1,EVCC,R2,DPTS2,U2
      DIMENSION TCD(5)
      GO TO (908,909),LL
  908 CALL DYNA (TQ,TCD,T)
      HP=T*3.14159*RPM/198000.
      LL=2
  909 HPVC=WVC*CP*DT*778.16/550.
      EVCC=100.*HP/HPVC
      RETURN
       END
C
      SUBROUTINE DYNA (TQ,TCD,T)
      DIMENSION TCD(5)
      DO 100 J=1,5
      IF(TCD(J)-TQ)100,101,101
  100 CONTINUE
  101 AJ=100*(J-1)
      T=AJ+100.*((TQ-TCD(J))/(TCD(J+1)-TCD(J)))
      RETURN
      END
C
      SUBROUTINE VEL (ALP2,DR,V1,V2,W1,W2,W2TH,T1,B1 ,T2P,TS2,PHII,B2,
     1VA2,TT2A,PSI,ZETA,THETA)
      COMMON  LL,K,GHG,CF1,T4,T5,WVC,TARE,PATM,PT2,PS2,PIN,PIR,EXP,DT,
     1CP,RPM,U1,EVCC,R2,DPTS2,U2
      AP=PIR/PIN
```

```
      B=T5*(1.-AP**EXP)
      DR=1.-B/DT
      G=2.*32.174*778.16*CP
      PHI=.889
      U1=4.7*RPM*3.14159/360.
      V1=PHI*SQRTF(G*B)
      A=57.29578
      ALP1=80.0/A
      VU1=V1*SINF(ALP1)
      WU1=VU1-U1
      VM1=V1*COSF(ALP1)
      W1=SQRTF(VM1**2+WU1**2)
      B1=A*ATANF(WU1/VM1)
      U2=R2*RPM*3.14159/360.
      T1=T5-PHI**2*B
      TTE=T1+(W1**2-U1**2+U2**2)/G
      PHII=(VM1/W1)**2
      T1P=T1+(1.-PHII)*(W1**2)/G
      T2P=T1P*(1./PIR**EXP)
      PD=PT2-PS2
C
C ITERATION TO DETERMINE TT2
C
  100 TT2 = T5 - (EVCC/100.) * DT
      V2=SQRTF(PD*2.*32.174*53.35*TT2/(PS2+PD*53.35/(778.16*CP)))
      VU2=V2*SINF(ALP2/A)
      DELH=(U1*VU1-U2*VU2)/(32.174*778.16)
      TT2A=T5-DELH/CP
      IF(ABSF(TT2-TT2A)-.05)104,104,101
  101 IF(TT2-TT2A)102,104,103
  102 EVCC=EVCC-.01
      GO TO 100
  103 EVCC=EVCC+.01
      GO TO 100
  104 VM2=V2*COSF(ALP2/A)
      WU2=VU2-U2
```

```
      W2=SQRTF(VM2**2+WU2**2)
      B2=(ATANF(WU2/VM2))*A
      TS2 = TT2 - (V2 ** 2)/G
      IF(TTE-T2P)2090,2090,105
 2090 PRINT 2091,K
 2091 FORMAT(1H1,4HERR5,I4)
      W2TH=.0
      W2=.0
      PSI=.0
      GO TO 106
  105 W2TH=SQRTF((TTE-T2P)*G)
      PSI=W2/W2TH
  106 ZETA=1.-PSI**2
      ZETA=1.-PSI**2
      VA2=VM2*COSF(THETA/A)
      RETURN
      END
C
      SUBROUTINE DISTEMP (V,TCJ,T)
      COMMON  LL,K,GHG,CF1,T4,T5,WVC,TARE,PATM,PT2,PS2,PIN,PIR,EXP,DT,
     1CP,RPM,U1,EVCC,R2,DPTS2,U2
      T=TCJ+36.53*V-.7638*V**2
      IF( T - 100.) 101,101,100
  100 T=TCJ+35.60*V-.2812*V**2
  101 T = T + 459.7
      RETURN
      END
C
      SUBROUTINE DISVEL(TT2,ALP2,THETA,VA2,V1,V2,W2,W2TH,T1,T2,TTE,T2P,
     2B2,ETA,PSI,ZETA,PHI)
      COMMON  LL,K,GHG,CF1,T4,T5,WVC,TARE,PATM,PT2,PS2,PIN,PIR,EXP,DT,
     1CP,RPM,U1,EVCC,R2,DPTS2,U2
      G=2.*32.174*778.16*CP
      A = 57.29578
      PD=PT2-PS2
      V2=SQRTF(PD*2.*32.174*53.35*TT2/(PS2+PD*53.35/(778.16*CP)))
```

```
      VU2=V2*SINF(ALP2/A)
      VM2=V2*COSF(ALP2/A)
      WU2 = VU2-U2
      W2 = SQRTF(VM2**2+WU2**2)
      B2=(ATANF(WU2/VM2))*A
      T2=TT2-(V2**2)/G
      TTE=T2+(W2**2)/G
      TR1=TTE-(U2**2-U1**2)/G
      PHI=1.
      AP=PIR/PIN
      B=T5*(1.-AP**EXP)
C
C ITERATION TO DETERMINE PHI
C
  100 V1= PHI*SQRTF(B*G)
      T1=T5-(V1**2)/G
      W1A=SQRTF(G*(TR1-T1))
      VM1=V1*COSF(80.0/A)
      VU1=V1*SINF(80.0/A)
      WU1=VU1-U1
      W1=SQRTF(VM1**2+WU1**2)
      IF(ABSF(W1-W1A)-1.)102,102,101
  101 PHI=PHI-.0001
      GO TO 100
  102 PHII=(VM1/W1)**2
      T1P=TR1-PHII*(W1**2)/G
      T2P=T1P*(1./PIR)**EXP
      T1=TR1-(W1**2)/G
      IF(TTE-T2P)103,103,104
  103 W2TH=.0
      W2=.0
      PSI=.0
      GO TO 105
  104 W2TH=SQRTF((TTE-T2P)*G)
      PSI=W2/W2TH
  105 ZETA=1.-PSI**2
```

```
      VA2=VM2*COSF(THETA/A)
      ETA=(T5-TT2)*100./DT
      RETURN
      END
C
      SUBROUTINE AVE (R,V,P,T,TT,W,NP,NPTS,CF1,X)
      DIMENSION R(60),V(60),P(60),T(60),TT(60),W(60),NP(60)
      MM=1
      NT=NPTS/2
      DO 100 K=1,60
      IF(NP(K))100,100,101
  101 RHO=P(K)*CF1/(T(K)*53.35)
      GO TO (102,103),MM
  102 MM=2
      DR=R(K)-1.76
      QWA=R(K)*V(K)*(W(K)**2)*RHO*TT(K)
      X=QWA*DR/(2.*144.)
      RT=R(K)
      NT=NT-2
      GO TO 100
  103 DR=R(K)-RT
      QWB=R(K)*V(K)*(W(K)**2)*RHO*TT(K)
      X=X+(QWA+QWB)*DR/(2.*144.)
      QWA=QWB
      RT=R(K)
      NT=NT-1
      IF(NT)104,104,100
  104 DR=2.94-RT
      X=X+QWA*DR/(2.*144.)
  100 CONTINUE
      RETURN
      END
      END
```

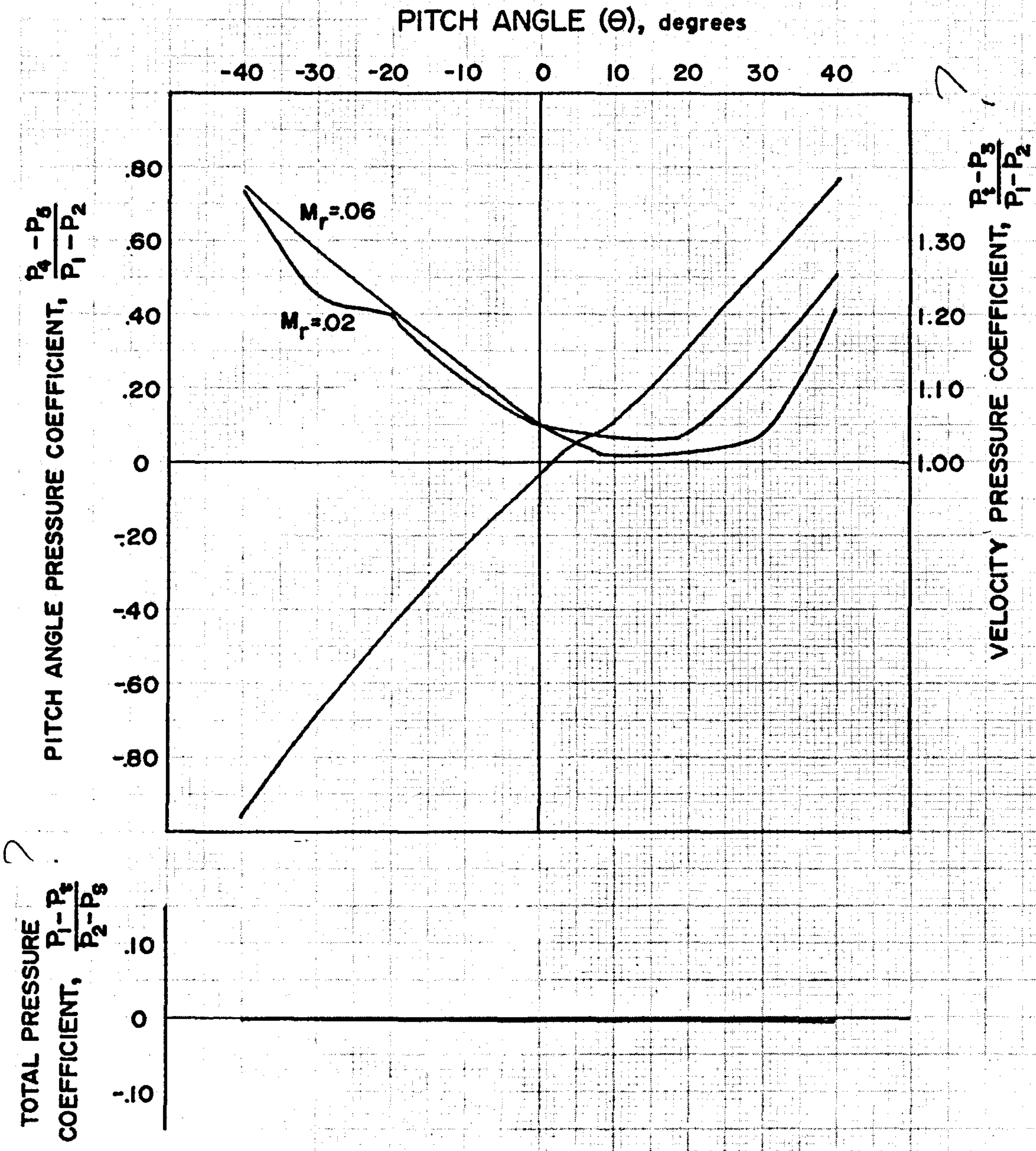

Fig. 2A

CALIBRATION OF DA-120 PROBE No. 538

LEFT SIDE OF TURBINE

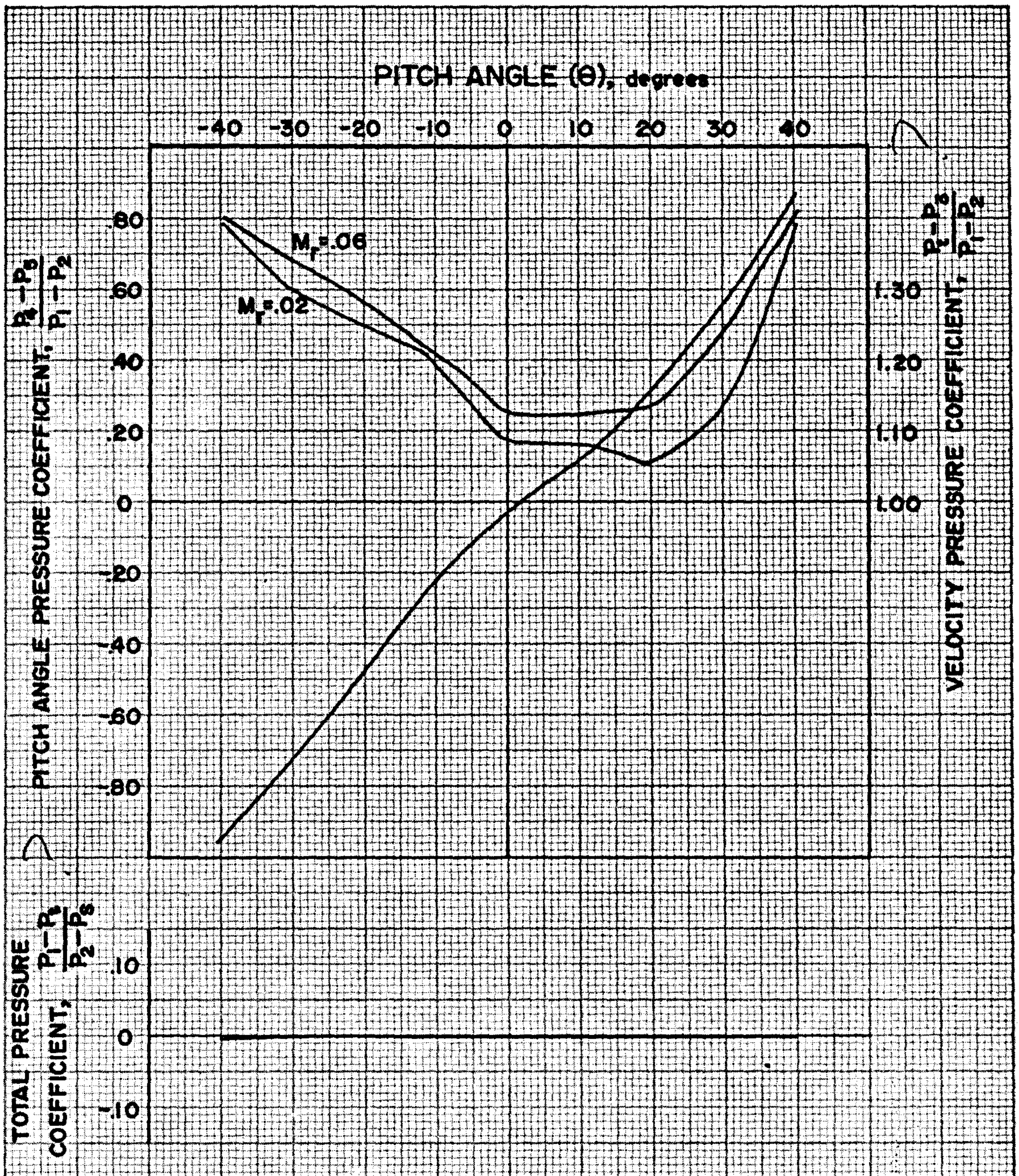

Fig. 3A
CALIBRATION OF DA-120 PROBE No. 539
RIGHT SIDE OF TURBINE

RUN	LOADING DIRECTION	TORQUE (in-lb)				
		0	100	200	300	400
1	increase	00.0	24.6	49.8	74.8	99.8
	decrease	00.1	25.3	50.3	75.4	99.8
2	increase	00.0	25.5	50.5	75.8	99.9
	decrease	00.1	25.7	50.8	75.6	99.9
3	increase	00.0	25.7	50.7	75.5	100.1
	decrease	00.1	25.8	50.9	75.8	100.1
4	increase	00.0	25.7	50.8	75.7	100.0
	decrease	00.0	25.9	50.9	75.7	100.0
5	increase	00.0	25.9	51.0	75.8	100.0
	decrease	00.2	26.0	51.0	75.8	100.0

TABLE A2

Torque Calibration Data

APPENDIX B

PROGRAM RADIAL

Program RADIAL evaluates the turbine performance with a meanstream line approach. A detailed description of the program is given in [10]. Several modifications were made to accommodate the present installation and instrumentation. A block diagram of the program is shown in Fig. B1 and a program listing is given in Table B1.

The number of tests points for each set of data was reduced from 40 to 10 to simplify the assembling of the input data. The torque calibration curve data was read into the program for each set of data since the curves varies significantly from run to run. Due to modifications explained later in this section, some of the input data READ statements were removed or changed.

The value of the specific gravity of mercury G_{Hg} at room temperature t_{rm} was corrected to agree with the tabulated data found in [6]. This relation, given by Eq. (A1), was placed in the main program instead of subroutine PRESS since the value of G_{Hg} is also used in subroutine FLOW.

Subroutine TEMP was limited to converting the total inlet temperature and the temperature ahead of the flow metering orifice to ^{o}R from the milli-volt readings of the thermocouples.

Subroutine FLOW remained unchanged except for the addition of the relations for converting the measured pressure ahead of the orifice to an absolute pressure using Eq. (A16),

and for correcting the measured pressure difference across the orifice for the tare reading using Eq. (A17).

Subroutine PRESS was modified to determine an average total turbine inlet pressure instead of the higher total inlet pressure measured by the Kiel probe located in the five-inch pipe. The average pressure is determined by iteration using the gas law, the continuity equation and the energy equation. The iteration is the same as that used in subroutine PRESS discussed in section A5. As a result of the modification, several other relations were changed. The new relations for the static turbine inlet pressure p_o and the static rotor inlet pressure p_1 are given in Eqs. (A20) and (A25), respectively. Since program RADIAL does not use the data from the discharge surveys, the static pressure at the rotor discharge is assumed to be the atmospheric pressure. Therefore, the total-to-static turbine pressure ratio is

$$\frac{P_{to}}{p_2} = \frac{P_{to}}{P_{atm} \quad \frac{G_{Hg}}{13.59}} \tag{B1}$$

and the ratio of the static pressures ahead of and after the rotor is

$$\frac{p_1}{p_2} = \frac{p_1}{P_{atm} \quad \frac{G_{Hg}}{13.59}} \tag{B2}$$

The factor $\mathcal{S}$ is

$$\mathcal{S} = \frac{C_f p_1}{(14.7)(144)} \tag{B3}$$

The modification also eliminated the need for the input of the total and static turbine inlet pressures measured on the water manometer board as seen in Fig. 2.

A new subroutine EDC was introduced to perform the computations of $c_{p(av)}$, γ_{ave}, ΔT_{is} and Δh_{is} that were originally computed in subroutine TEMP. This change was necessary since the iteration for P_{to} in PRESS required T_{to} and the iteration for γ_{ave} required the pressure ratio P_{to}/p_2.

Subroutine DYNA was rewritten to determine the torque from the dynamometer calibration data obtained prior to each run. A description of the subroutine is given in Appendix A(7).

In subroutine BLADE the expression for the carry-over coefficient Φ_i was changed. It was assumed that the useful kinetic energy at the rotor inlet is $\Phi_i W_1^2/2gJc_p$ and that $\Phi_i = V_{m1}^2/W_1^2$ 11 .

No changes were made to either subroutines TURB or ZETA, or to the output.

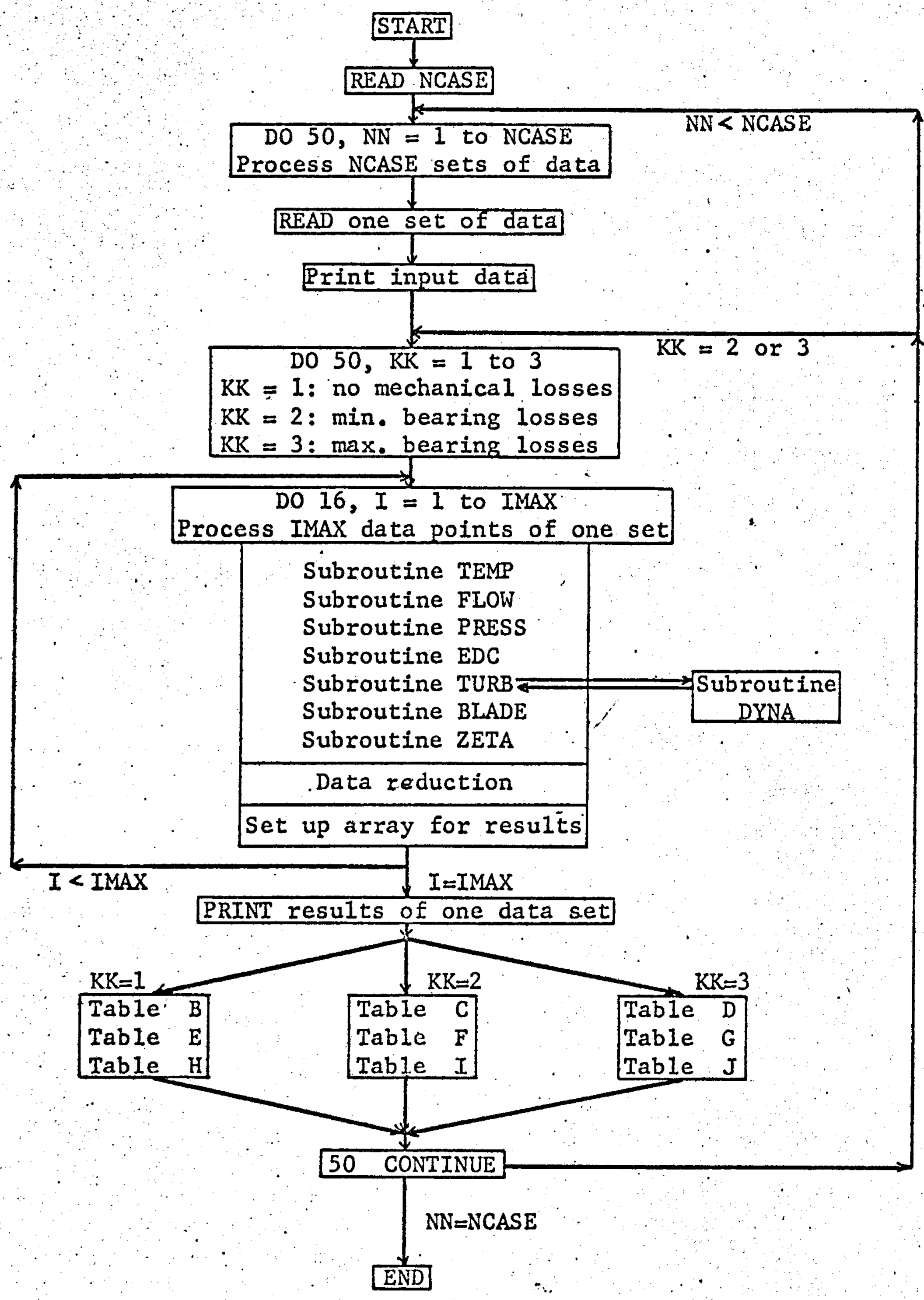

Fig. B1

Block Diagram of Program RADIAL

TABLE B1

LISTING FOR PROGRAM RADIAL

```
..JOB0571F,RILEY
      PROGRAM RADIAL
C REDUCES TEST DATA OF RADIAL TURBINE IN ACCORDANCE WITH NASA METHOD
C AND ESTABLISHES ROTOR LOSS COEFFICIENTS,DISCHARGE ANGLES,DEGREE OF
C REACTION AND FLOW COEFFICIENTS,FOR SPECIFIED GUIDE VANE LOSS AND
C DIFFERENT BEARING LOSSES. PROCESSES ANY NO.OF DATADECKS(36 CARDS/DECK)
      DIMENSION NRU(10),NPT(10),IER(10),PUFL(10),PUVC(10),
     1P5(10),DPFL(10),DPVC(10),RPM(10),TQ(10),TCJ(10),V4(10),V5(10),
     2              BA(10),TARE(10),P1(10),P16(10),TRM(10),TCD(5),
     3 PINP(10),RPP(10),           UCP(10),HKP(10),WFLP(10),WVCP(10),
     4EFLP(10),EVCP(10),HPP(10),TP(10),DRP(10),B1P(10),R2AP(10),
     5A2FP(10),A2VP(10),VRFP(10),VRVP(10),ZNFP(10),ZNVP(10),ZRFP(10),
     6ZRVP(10),ZLF(10),ZLV(10) ,R2MP(10), NRUP(10), NPTP(10)
      COMMON T4,T5,GHG,CF1,WFL,WVC,TAR,PIN,PIR,DEL,GAM,EXP,CP,DHIS,RP,T,
     1EFL,EVC
C  READ  INPUT DATA
      READ 1001 ,NCASE
      DO    50   NN= 1,NCASE
      READ 1003 ,NRU
      READ 1003 ,NPT
      READ 1006 ,IER
      READ 1001 ,IMAX
      READ 1009 ,PUFL
      READ 1009 ,PUVC
      READ 1009 ,P5
      READ 1009 ,DPFL
      READ 1009 ,DPVC
      READ 1015 ,RPM
      READ 1009 ,TQ
      READ 1009 ,TCJ
```

```
      READ 1009 ,V4
      READ 1009 ,V5
      READ 1009 ,BA
      READ 1009 ,TRM
      READ 1009 ,TARE
      READ 1009 ,P1
      READ 1009, P16
      READ 1005,TCD
C PRINT OUT TABLE A OF INPUT DATA
      PRINT 1000
      CONTINUE
      PRINT 1002
      PRINT 1003, NRU
      PRINT 1045
      PRINT 1004
      PRINT 1003, NPT
      PRINT 1045
      PRINT 1008
      PRINT 1009, PUFL
      PRINT 1045
      PRINT 1010
      PRINT 1009, PUVC
      PRINT 1045
      PRINT 1011
      PRINT 1009, P5
      PRINT 1045
      PRINT 1012
      PRINT 1009, DPFL
      PRINT 1045
      PRINT 1013
      PRINT 1009, DPVC
      PRINT 1045
      PRINT 1014
      PRINT 1015, RPM
      PRINT 1045
      PRINT 1016
```

```
      PRINT 1009, TQ
      PRINT 1045
      PRINT 1017
      PRINT 1009, TCJ
      PRINT 1045
      PRINT 1018
      PRINT 1009, V4
      PRINT 1045
      PRINT 1019
      PRINT 1009, V5
      PRINT 1045
      PRINT 1022
      PRINT 1009,BA
      PRINT 1045
      PRINT 1023
      PRINT 1009,TRM
      PRINT 1045
      PRINT 1024
      PRINT 1009, TARE
      PRINT 1045
      PRINT 1025
      PRINT 1009, P1
      PRINT 1045
      PRINT 1044
      PRINT 1009, P16
C BEGINNING OF PROCESSING OF IMAX DATA POINTS PER SET FOR KK=1,2,OR 3
      DO  50  KK=1,3
      K=1
      J = 1
      JM = 0
      DO 16   I=1,IMAX
      IF(I- IER(K)) 2,2,1
    1 K=K +1
    2 B = BA(K)
      TAR = TARE(K)
      PUF = PUFL(I)
```

```
      PUV = PUVC(I)
      DPF = DPFL(I)
      DPV = DPVC(I)
      P51 = P5(I)
      P11 = P1(I)
      P161=P16(I)
      TJ  = TCJ(I)
      VV4= V4(I)
      VV5= V5(I)
      RP= RPM(I)
      TR= TQ(I)
       GHG = 13.638 - 1.354E-3*TRM(I)
      CF1=69.892*GHG/13.59
      CALL TEMP(VV4,VV5,TJ)
      CALL FLOW (PUF,PUV,DPF,DPV,B)
      CALL PRESS (B,P51,P161,P11)
      CALL EDC (THE)
      CALL TURB(KK,TR,HP,UC,HK,TCD)
      CALL BLADE(DR,B1,R2A,PSIFL,PSIVC,A2FL,A2VC,VRFL,VRVC,TE,PE,KLM,R2
     1M)
      AA = SQRTF(53.35/32.174)
      IF(T5) 2000,2001,2001
 2000 PRINT 2002, I,T5
 2002 FORMAT(4H1060,I4,F8.3)
 2001 CONTINUE
      W1 = WFL * SQRTF(T5)* AA / (DEL*14.7)
      W=  W1/ 4.470
      PR=PIN/PIR
      CALL ZETA( W, PR, ZEN1)
      W =  W * WVC/WFL
      CALL ZETA(W , PR, ZEN2)
      IF(TE/PE) 2010,2011,2011
 2010 PRINT 2012, I, TE, PE
 2012 FORMAT(4H1120, I4,2F8.3)
 2011 CONTINUE
      W=   W1 * SQRTF(TE)/(PE)
```

```
      W=  W/12.865
      PR = PE * PIN
      CALL ZETA (W,PR,ZER1)
      W=  W * WVC/WFL
      CALL ZETA (W,PR,ZER2)
C REDUCTION OF DATA FOR TABLES B,C, OR D
      RPP(I) = RPM(I)/THE
      PINP(I)=PIN
      UCP(I) = UC
      HKP(I) = HK
      WFLP(I)= WFL * THE/DEL
      WVCP(I)= WVC * THE/DEL
      EFLP(I)= EFL
      EVCP(I)= EVC
      HPP(I) = HP/( THE * DEL)
      TP(I)  = T/ DEL
C VALUES FOR TABLES E,F, OR G
      DRP(I) = DR
      B1P(I) = B1
      R2AP(I)= R2A
      A2FP(I)= A2FL
      A2VP(I) = A2VC
      VRFP(I) = VRFL
      VRVP(I) = VRVC
      GO TO ( 3001, 3000), KLM
 3000 R2MP(J) = R2M
      NRUP(J) = NRU(I)
      NPTP(J) = NPT(I)
      J = J+ 1
      JM = JM + 1
 3001 CONTINUE
C VALUES FOR  TABLES H,I, OR J
      ZNFP(I) = ZEN1
      ZNVP(I) = ZEN2
      ZRFP(I) = ZER1
      ZRVP(I) = ZER2
```

```
      ZLF(I) = 1. - PSIFL ** 2
      ZLV(I) = 1. -  PSIVC **2
      CONTINUE
      CONTINUE
      CONTINUE
      CONTINUE
      CONTINUE
      CONTINUE
   16 CONTINUE
     GO TO (10,20,30) , KK
C PRINT TABLE  B   (KK=1)
   10 PRINT 1026
     PRINT 1027
     PRINT 1035
     PRINT 1036
     GO TO 40
C  PRINT TABLE E  (KK=1)
   11 PRINT 1026
     PRINT 1030
     PRINT 1035
     PRINT 1037
     GO TO  42
C  PRINT TABLE H   (KK=1)
   12 PRINT  1026
     PRINT  1033
     PRINT  1035
     PRINT  1038
     GO TO  44
C PRINT  TABLE C (KK=2)
   20 PRINT  1026
     PRINT  1028
     PRINT  1035
     PRINT  1036
     GO TO 40
C  PRINT TABLE  F  (KK=2)
   21 PRINT  1026
```

```
      PRINT  1031
      PRINT  1035
      PRINT  1037
      GO TO  42
C PRINT TABLE  I  (KK=2)
   22 PRINT  1026
      PRINT  1133
      PRINT  1035
      PRINT  1038
      GO TO  44
C PRINT  TABLE  D  (KK=3)
   30 PRINT  1026
      PRINT  1029
      PRINT  1035
      PRINT  1036
      GO  TO   40
C PRINT TABLE  G (KK= 3)
   31 PRINT  1026
      PRINT  1032
      PRINT  1035
      PRINT  1037
      GO TO   42
C PRINT TABLE  J (KK=3)
   32 PRINT   1026
      PRINT   1034
      PRINT   1035
      PRINT   1038
      GO  TO  44
   40 DO  41 I=1,IMAX
   41 PRINT 1039,NRU(I),NPT(I),RPP(I),PINP(I),HKP(I),UCP(I),WFLP(I),
     1EFLP(I),WVCP(I),EVCP(I),HPP(I),TP(I)
      GO TO ( 11, 21, 31 ), KK
   42 DO  43 I=1,IMAX
   43 PRINT 1040, NRU(I),NPT(I),RPP(I),PINP(I),UCP(I),DRP(I),B1P(I),
     1R2AP(I),A2FP(I),A2VP(I),VRFP(I),VRVP(I)
      IF(JM) 3200,3200,3100
```

```
3100 PRINT 1042
     DO 3101  J=1, JM
3101 PRINT 1043, NRUP(J),  NPTP(J), R2MP(J)
3200 CONTINUE
     GO TO ( 12,22 , 32 ), KK
  44 DO  45  I=1,IMAX
  45 PRINT 1041, NRU(I),NPT(I),RPP(I),PINP(I),UCP(I),ZNFP(I),ZNVP(I),
    1ZRFP(I),ZRVP(I),ZLF(I),ZLV(I)
  50 CONTINUE
      CONTINUE
C FORMATS FOR READ IN AND PRINT OUTS
1000 FORMAT(1H1//3X14HPROGRAM RADIAL50X10HM.W. RILEY///24X31HAIR TESTS
    1OF ICP RADIAL TURBINE//21X38HTABLE           INPUT OF MEASURED DAT
    2A//)
1001 FORMAT(I8)
1002 FORMAT(2X11HRUN NUMBERS51X16H(CARDS 2 AND 2A)/)
1003 FORMAT(10I8)
1004 FORMAT(2X11HTEST POINTS51X16H(CARDS 3 AND 3A)/)
1005 FORMAT(5F7.1)
1006 FORMAT(10I8)
1008 FORMAT(2X46HUPSTREAM ORIFICE PRESSURE  CM.HG (FLANGE TAPS)17X15H(C
    1ARDS 6 AND 7)/)
1009 FORMAT(10F8.2)
1010 FORMAT(2X54HUPSTREAM ORIFICE PRESSURE  CM.HG (VENA CONTRACTA TAPS)
    109X15H(CARDS 8 AND 9)/)
1011 FORMAT(2X42HSTATIC PRESSURE IN 5 IN. INLET PIPE  CM.HG19X17H(CARDS
    1 10 AND 11)/)
1012 FORMAT(2X48HORIFICE PRESSURE DIFFERENCE  CM.HG (FLANGE TAPS)13X17H
    1(CARDS 12 AND 13)/)
1013 FORMAT(2X56HORIFICE PRESSURE DIFFERENCE  CM.HG (VENA CONTRACTA TAP
    1S)5X17H(CARDS 14 AND 15)/)
1014 FORMAT(2X18HTURBINE SPEED  RPM43X17H(CARDS 16 AND 17)/)
1015 FORMAT(10F8.0)
1016 FORMAT(2X20HTORQUE SCALE READING41X17H(CARDS 18 AND 19)/)
1017 FORMAT(2X32HCOLD JUNCTION TEMPERATURE  DEG.F29X17H(CARDS 20 AND 21
    1)/)
```

```
1018 FORMAT(2X27HTHERMOCOUPLE 4 IN. PIPE  MV34X17H(CARDS 22 AND 23)/)
1019 FORMAT(2X27HTHERMOCOUPLE 5 IN. PIPE  MV34X17H(CARDS 24 AND 25)/)
1022 FORMAT(2X29HBAROMETER FOR EACH RUN  IN.HG40X9H(CARD 30)/)
1023 FORMAT(2X44HCONTROL ROOM TEMPERATURE FOR EACH RUN  DEG.F25X9H(CARD
    1 31)/)
1024 FORMAT(2X29HTARE OF MICROMANOMETER  CM.HG40X9H(CARD 32)/)
1025 FORMAT(2X50HAVERAGE READING OF PRESSURE AHEAD OF ROTOR  IN.H2O11X1
    17H(CARDS 33 AND 34)/)
1044 FORMAT(2X33HTUBE 16 OF MANOMETER BOARD  IN.HG28X17H(CARDS 35 AND 3
    16)/)
1026 FORMAT(1H1//3X14HPROGRAM RADIAL50X10HM.W. RILEY///24X31HAIR TESTS
    1OF ICP RADIAL TURBINE///)
1027 FORMAT(9X62HTABLE        OVERALL PERFORMANCE VALUES WITHOUT BEARIN
    1G LOSSES//)
1028 FORMAT(6X67HTABLE        OVERALL PERFORMANCE VALUES WITH MINIMUM B
    1EARING LOSSES//)
1029 FORMAT(6X67HTABLE        OVERALL PERFORMANCE VALUES WITH MAXIMUM B
    1EARING LOSSES//)
1030 FORMAT(13X54HTABLE        BLADING PARAMETERS WITHOUT BEARING LOSSE
    1S//)
1031 FORMAT(10X59HTABLE        BLADING PARAMETERS WITH MINIMUM BEARING
    1LOSSES//)
1032 FORMAT(10X59HTABLE        BLADING PARAMETERS WITH MAXIMUM BEARING
    1LOSSES//)
1033 FORMAT(8X64HTABLE        LOSS COEFFICIENTS OF BLADING WITHOUT BEAR
    1ING LOSSES//)
1133 FORMAT(6X69HTABLE        LOSS COEFFICIENTS OF BLADING WITH MINIMUM
    1 BEARING LOSSES//)
1034 FORMAT(6X69HTABLE        LOSS COEFFICIENTS OF BLADING WITH MAXIMUM
    1 BEARING LOSSES//)
1035 FORMAT(13X54HREDUCED TO STANDARD AIR IN ACCORDANCE WITH NASA METHO
    1D/6X68HTOTAL INLET PRESSURE =14.7 PSIA,TOTAL INLET TEMPERATURE =51
    28.7 DEG.R/6X67HGAMMA =1.4,SPECIFIC HEAT CP AT CONSTANT PRESSURE =0
    3.24 BTU/(LBM,DF)///)
1036 FORMAT(43X6HFLANGE4X14HVENA CONTRACTA/40X26HORIFICE TAPS  ORIFICE
    1TAPS//2X3HRUN2X2HPT2X5HSPEED3X6HPRESS.1X4HHEAD3X4HU/CO2X4HFLOW3X5H
```

```
     2EFFI-2X4HFLOW 3X5HEFFI-3X5HPOWER1X6HTORQUE/19X5HRATIO2X6HCOEFF.7X4
     3HRATE3X7HCIENCY 4HRATE3X6HCIENCY//12X3HRPM24X5HLBM/S3X4HPCT.2X5HLB
     4M/S3X4HPCT.4X2HHP4X5HFT-LB//)
 1037 FORMAT(80H RUN PT SPEED  PRESS. U/CO  DEGREE  ANGLE AVERAGE DISCHA
     1RGE ANGLE VELOCITY RATIO/8X12H         RATIO10X2HOF4X13HBETA1  RADIU
     2S5X7HALPHA 29X6HVM2/U1/27X8HREACTION8X37HRATIO  FLANGE  VENA.C  FL
     3ANGE  VENA.C/9X3HRPM25X27HDEG.  R2/R1    DEG.    DEG.//)
 1038 FORMAT(77H RUN PT SPEED  PRESS. U/CO STATOR LOSS COEFFICIENT    RO
     1TOR LOSS COEFFICIENTS/8X12H        RATIO8X52HFOR AREA CALCULATION
     2   FOR AREAS    FOR EFFICIENCY/9X3HRPM18X50HFLANGE     VENA.C    F
     3LANGE  VENA.C FLANGE  VENA.C//)
 1039 FORMAT(I4,I5,F8.0,2F7.3,F6.3,F7.3,F7.2,F7.3,F7.2,F8.2,F7.2)
 1040 FORMAT(I3,I4,F7.0,2F6.3,F7.3,F8.1,F6.3,F9.2,F8.2,F7.3,F8.3)
 1041 FORMAT(I3,I4,F7.0,2F6.3,F9.3,F11.3,F10.3,F7.3,2F8.3)
 1042 FORMAT ( 15X//)
 1043 FORMAT(     I3,I4,3X25HNO FLOW TO  RADIUS   R2 =F6.3,4H IN.2X20HOF
     1 DISCHARGE ANNULUS)
 1045 FORMAT(/)
C NOTE.FOR TABLES B,C,D USE FORMATS 1035,1036(AND 1039 FOR DATA)
C FOR TABLES E,F,G USE FORMATS      1035,1037(AND 1040 FOR DATA)
C FOR TABLES H,I,J USE FORMATS      1035,1038(AND 1041 FOR DATA)
      PRINT 1510
 1510 FORMAT(1H1)
      END
C
      SUBROUTINE TEMP(V4,V5,TCJ)
C CALCULATION OF TEMPERATURE FROM THERMOCOUPLE READING
      COMMON T4,T5,GHG,CF1,WFL,WVC,TAR,PIN,PIR,DEL,GAM,EXP,CP,DHIS,RPM,T
     1,EFL,EVC
      V=V4
      K=1
  100 T = TCJ + 44.41 * V + .2185 * V ** 2
      IF( T - 100.) 102,102,101
  101 T = TCJ + 45.24 * V - .3295 * V ** 2
  102 T=  T + 459.7
      IF(K-1)103,103,104
```

```
  103 K= 2
      V= V5
      T4 =  T
      GO TO 100
  104 T5 =  T
      RETURN
      END
C
      SUBROUTINE FLOW (PUFL,PUVC,DPFL,DPVC,B)
C CALCULATES FLOW RATE FROM ORIFICE MEASUREMENTS WITH FLANGE AND VENA
C CONTRACTA TAPS
      COMMON T4,T5,GHG,CF1,WFL,WVC,TAR,PIN,PIR,DEL,GAM,EXP,CP,DHIS,RPM,T
     1,EFL,EVC
      PFL = (PUFL - TAR + B * 2.54) * GHG/13.59
      PVC = (PUVC - TAR + B * 2.54) * GHG/13.59
      DFL=(DPFL-TAR)*GHG/13.59
      DVC=(DPVC-TAR)*GHG/13.59
      A = 1. +1.E-5*(T4 -530.)
      Z = 1.9 +2.4E-3 * (T4 -560.)
      Y = 1. - .351 * DFL/PFL
      IF( PFL* DFL/T4 ) 2060,2061,2061
 2060 PRINT 2062, I, PFL,DFL,T4
 2062 FORMAT(4H4180,I4,3F8.3)
 2061 CONTINUE
      WFL = .9002* A * Y * SQRTF(PFL * DFL/T4)
      X   = WFL * .812/Z
      WFL = (1. +.00142/X)* WFL
      Y=  1. - .351* DVC/PVC
      IF(PVC*DVC/T4 )  2070,2071,2071
 2070 PRINT 2072, I,PVC,DVC,T4
 2072 FORMAT(4H4220, I4,3F8.3)
 2071 CONTINUE
      WVC =  .9057*A * Y * SQRTF(PVC * DVC/ T4)
      X   = WVC  *.812/Z
      WVC = (1. + .00114/X)* WVC
      RETURN
```

```
      END
C
      SUBROUTINE PRESS (B,P5P,P16,P1)
C CALCULATES ABSOLUTE PRESSURE AHEAD OF TURBINE AND PRESSURE RATIOS
C WITHIN TURBINE
      COMMON T4,T5,GHG,CF1,WFL,WVC,TAR,PIN,PIR,DEL,GAM,EXP,CP,DHIS,RPM,T
     1,EFL,EVC
      A=T5-459.7
      CP=.23943+3.4E-6*A+2.E-8*A**2
      TT=T5
      PS5=(B+(P5P-TAR)/2.54)*GHG/13.59
  108 RHO=PS5*CF1/(TT*53.35)
      VO =WVC/(RHO*3.14159*6.25/144.)
      TO=T5-(VO **2)/(2.*32.174*778.16*CP)
      DDT=TT-TO
      TT=TO
      IF(ABSF(DTT)-.01)109,109,108
  109 PTO=PS5+RHO*(VEL**2)/(2.*32.174*CF1)
      DEL=PTO*CF1/(144.*14.7)
      PIN=PTO/(B*GHG/13.59)
      PIR=(PS5-(P16-P1)*GHG/13.59)/(B*GHG/13.59)
      RETURN
      END
C
      SUBROUTINE EDC (THE)
C CALCULATION OF AVERAGE CP AND GAM AND SQ. ROOT OF TEMPERATURE RATIO
C (THETA) AND ISENTROPIC ENTHALPY DROP
      COMMON T4,T5,GHG,CF1,WFL,WVC,TAR,PIN,PIR,DEL,GAM,EXP,CP,DHIS,RPM,T
     1,EFL,EVC
      A =  T5 -459.7
  105 GA =  1.4018   - 2.E-5 * A
      EX =  (GA -1.)/GA
      DT =  T5 *(1. -1./PIN ** EX)
      AA=  T5 - 459.7 - DT/2.
      AAA  = ABSF(AA -A)
      IF(AAA -1.0)  107,107,106
```

```
  106 A = AA
      GO TO 105
  107 GAM = GA
      EXP = EX
      CP = .23943 + 3.4E-6*AA +2.E-8 *AA**2
      DHIS = CP * DT
      IF (GAM * T5) 2050,2051,2051
 2050 PRINT 2052, I, GAM, T5
 2052 FORMAT(4H3920,I4,2F8.3)
 2051 CONTINUE
      THE  = SQRTF( GAM * T5/(1.4 * 518.7))
      RETURN
      END
C
      SUBROUTINE TURB (KK,TQ,HP,UC,HK,TCD)
C CALCULATES U/CO AND HEAD COEFFICIENT KIS,TURBINE POWER,EFFICIENCIES
C AND NET TORQUE FOR DIFFERENT BEARING LOSSES,KK=1 NONE,KK=2 MIN,KK=3MAX
      DIMENSION TCD(5)
      COMMON T4,T5,GHG,CF1,WFL,WVC,TAR,PIN,PIR,DEL,GAM,EXP,CP,DHIS,RPM,T
     1,EFL,EVC
       U= 3.14159 * RPM * 9.40  /720.
       IF(U ) 120,120,121
  121  HK = DHIS * 5.0073E+4/ U**2
      IF (HK) 2080,2081,2081
 2080 PRINT 2082, I, DHIS
 2082 FORMAT(4H4720,  I4,F8.3)
 2081 CONTINUE
       UC =  SQRTF( 1./HK)
       CALL DYNA (TQ,TCD,T)
       HP = T * 3.14159 * RPM /(360.* 550.)
       HPFL = WFL *  DHIS * 778.16/550.
       HPVC = WVC *  DHIS * 778.16/550.
       GO TO (110,111,114),KK
  110  EFL = 100. * HP/HPFL
       EVC = 100. * HP/HPVC
       T= HP* 16500./(3.14159 * RPM)
```

```
      RETURN
 111  IF( RPM -10500.)112 ,112 ,113
 112  HPL=-.795 +(RPM/1000.)* .17143
      GO  TO  117
 113  HPL =-.795 +(RPM/1000.) *.17143 - 8.571E-3*(RPM/1000.-10.5)**2
      GO  TO  117
 114  IF(RPM -10500.) 115,115,116
RPM ≤ 10500
 115  HPL = -.6 + (RPM/1000.) * .17143
     GO TO 117
RPM > 10500
 116  HPL= -.6 +(RPM/1000.)*.17143- 4.898E-3*(RPM/1000.-10.5)**2
 117  HP = HP + HPL
     GO TO 110
 120 HK = 99.999
      UC =0.0
     T = 4.*TQ
      HP = 0.0
      EFL =0.0
      EVC =0.0
      T = T/12.
      RETURN
     END
C
     SUBROUTINE DYNA (TQ,TCD,T)
C CALCULATES THE TORQUE FROM THE TORQUE CALIBRATION DATA
     DIMENSION TCD(5)
     DO 100 J=1,5
     IF(TCD(J)-TQ)100,101,101
 100 CONTINUE
 101 AJ=100*(J-1)
     T=AJ+100.*((TQ-TCD(J))/(TCD(J+1)-TCD(J)))
     RETURN
     END
C
     SUBROUTINE BLADE(DR,B1,R2A,PSIFL,PSIVC,A2FL,A2VC,VRFL,VRVC,TE,PE,
    1KLM,R2M)
C CALCULATES CONDITIONS IN ROTOR AND ESTABLISHES PSI TO MATCH MEASURED
```

```
C      EFFICIENCES,ANGLES BEAT1,ALPHA2,R2AV,DEGREE OF REACTION
       DIMENSION  W22(60),W2M(60),E1(60),E2(60)
       COMMON T4,T5,GHG,CF1,WFL,WVC,TAR,PIN,PIR,DEL,GAM,EXP,CP,DHIS,RPM,T
      1,EFL,EVC
       A = PIR/PIN
       B = T5 *(1. - A ** EXP)
       DT = T5 * (1. - 1./PIN **EXP)
       DR = 1. - B/DT
       G = 2.*32.174 * 778.16 * CP
       IF (CP)  2090,2091,2091
  2090 PRINT  2092,I, CP
  2092 FORMAT(4H3060,I4,F8.3)
  2091 CONTINUE
       PHI=.889
       V1= PHI * SQRTF(G * B)
       T1= T5 - PHI**2 * B
       U1=  3.14159 * RPM * 9.4 /720.
       ALP1=80.0/57.29578
       VU1=V1*SINF(ALP1)
       VM1=V1*COSF(ALP1)
       WU1= VU1- U1
       W1 = SQRTF(VM1**2 + WU1**2)
       B1 = 57.29578 * ATANF(WU1/VM1)
       PHII=(VM1/W1)**2
       TR1 = T1 + (W1**2)/G
       T1P=TR1-PHII*(W1**2)/G
       T2P=T1P*(1./PIR**EXP)
       C = G * (TR1 - T2P) - U1 ** 2
       KLM = 1
        IF(RPM) 321,321,320
   321 W2T2 = C
        GO TO 322
   320 D =  (U1/4.7)**2
       DO  300  K=1,60
       AK = K
       R2 = 1.76 +(AK-1.)*.02
```

```
      W22(K) = C +  D * R2**2
      IF ( W22(K)) 350 , 351 , 351
  350 E1(K) = 0.0
      E2(K) = 0.0
      R2M = R2
      KLM = 2
      GO TO 300
  351 CONTINUE
      W2M(K) = SQRTF(W22(K))* COSF((67. +(AK-1.)*(2.85/59.))/57.29578)
      E1(K)  = R2 * W2M(K) * W22(K)
      E2(K)  = R2 * W2M(K)
  300 CONTINUE
      E1(1)= .5 * E1(1)
      E1(60)= .5 * E1(60)
      E2(1) = .5 * E2(1)
      E2(60)= .5 * E2(60)
      S1 = 0.0
      S2 = 0.0
      DO 301 K= 1,60
      S1= S1 + E1(K)
  301 S2= S2 + E2(K)
      W2T2 = S1/S2
      R2A    =(SQRTF((W2T2 - C)/D))/4.7
      B2A = 67. + 2.85 *(R2A* 4.7 - 1.76)/1.18
       GO TO 330
  322 R2A = .5155
       B2A = 68.6
C DETERMINES VELOCITY RATIOS PSI OF ROTOR
  330 KL = 1
      U2 = U1* R2A
  500 PSI = 1.
  501 VU2 = U2 - PSI * SINF(B2A/57.29578)* SQRTF(W2T2)
      IF(U1)  510,510,511
  510 GO TO (521,522),KL
  521 TAF =(WFL/32.174) *(4.7/12.) *(VU1 - R2A * VU2)
      IF( TAF - T) 505,505,504
```

```
  511 ET = ((U1 * VU1 - U2 * VU2)/(.5 * G))/DT
      GO TO (502,503),KL
  502 IF (ET- EFL   /100.) 505,505,504
  504 PSI = PSI -.001
      GO TO 501
  505 KL =  2
      PSIFL  = PSI
      A2FL   =57.29578*ATANF(VU2/(PSI*COSF(B2A/57.29578)*SQRTF(W2T2)))
      GO TO 500
  522 TAV = (WVC/32.174) * ( 4.7/12.) * (VU1 - R2A * VU2)
      IF(TAV - T) 506,506,504
  503 IF (ET -EVC   /100.) 506,506,504
  506 PSIVC  = PSI
      A2VC   =57.29578*ATANF(VU2/(PSI*COSF(B2A/57.29578)*SQRTF(W2T2)))
      WM2  = COSF(B2A/57.29578)* SQRTF(W2T2)
       IF(U1) 530,530,531
  530 VRFL =PSIFL * WM2 /VU1
      VRVC = PSIVC * WM2 / VU1
       GO TO 532
  531 VRFL =  PSIFL* WM2/U1
      VRVC =  PSIVC* WM2/U1
  532 TE = T2P/T5 + W2T2/(G * T5)
      PE = (TE * T5/T2P) **(1./EXP)/PIN
      RETURN
      END
C
      SUBROUTINE  ZETA ( W, PR, ZZ)
C CALCULATES ACTUAL LOSS COEFFIENT OF  FLOW WITH FRICTION THROUGH A
C KNOWN DISCHARGE  AREA WITH ACCURACY OF 0.001 OF LOSS COEFF.
      COMMON T4,T5,GHG,CF1,WFL,WVC,TAR,PIN,PIR,DEL,GAM,EXP,CP,DHIS,RPM,T
     1,EFL,EVC
      PSIF(A,C) =SQRTF((2.*GAM/(GAM-1.))*(1./A**(2.*(1.+ C*(GAM-1.))/
     1GAM)-1./A**(( GAM+1.+C*(GAM-1.))/GAM)))
      X = 1./PR **((GAM -1.)/GAM)
      AA1=PSIF(PR,0.0)
      IF (AA1-W )704,700,701
```

```
700 ZZ = 0.0
    RETURN
701 D = 0.001
702 AA1 = PSIF(PR, D)
    IF (AA1-W ) 707 ,707,703
703 D = D + .001
    GO TO  702
704 D = - .001
705 AA1 = PSIF(PR,D )
    IF( AA1-W ) 706 ,707,707
706 D = D -.001
    GO  TO  705
707 ZZ = (X**(1.-D)- X)/(1. - X)
    RETURN
    END
    END
```

APPENDIC C

PROGRAM SCROLL

C1 General

Program SCROLL was written to determine the losses in the scroll and guide vanes and the absolute rotor inlet flow angle. The program can process any number of runs, with a maximum of 10 sets of data per run. A block diagram of the program is shown in Fig. C1 and a program listing is given in Table C1.

The program initially reads the number of runs (NRUNS) which is used as an upper limit for the first DO loop. Within this DO loop, the number of sets of data (NSETS) and the input data for the run are read into the program. The input data is then printed out and the processing of each set of data is commenced using a DO loop with index K varying from 1 to NSETS. A description of the main program is given below.

The value of the specific gravity of mercury G_{Hg} at room temperature t_{rm} and the factor C_f for converting in-Hg to lb/ft^2 are determined by Eqs. (A2) and (A3). The value of the specific gravity of water G_{H2O} at room temperature is

$$G_{H2O} = 1.00013 + 7.8(10^{-5})\ t_{rm} - 1.4(10^{-6})\ t_{rm}^{\ 2} \qquad \text{(C1)}$$

The specific gravity relations were obtained from tabulated data found in [6].

After the data for one run has been processed by the four subroutines discussed in sections C2 through C4 the data is printed out and the data for the next run is read into the program.

C2 Subroutine TEMP and FLOW

Subroutine TEMP calculates the total temperature ahead of the flow measuring orifice and the turbine inlet from chromel-alumel thermocouple readings. Subroutine FLOW calculates the turbine flow rate using the pressures obtained with the vena contracta taps of the orifice. Both subroutines are the same as those used in program SURVEY.

C3 Subroutine PRESS

Subroutine PRESS determines the static pressure ahead of the dummy rotor and the ratio of the total pressure at the turbine inlet to the static pressure ahead of the dummy rotor.

The static pressure at the rotor inlet p_1 is obtained from the average of the measured rotor inlet pressure $(h_{atm} - h_1)$, where h_1 is the average of the pressure readings and h_{atm} is the reference pressure. Thus p_1 is

$$p_1 = \frac{P_{atm}(G_{Hg}) - (h_{atm} - h_1)G_{Hg}}{13.59} \tag{C2}$$

The total pressure at the turbine inlet P_{to} is determined by iteration using the gas law, the continuity equation and the energy equation. It is the same iteration as used in subroutine PRESS discussed in section A5.

C4 Subroutine PSI

Subroutine PSI determines the inlet velocity coefficient and the absolute rotor inlet flow angle.

From the theorem of angular momentum[1] for a steady flow that does not have a whirl component at the rotor discharge ($V_{u2} = 0$), the moment M exerted on the dummy rotor of radius 4.75 inches is

$$M = \dot{W}_{vc} \frac{4.75 \, V_{u1}}{g} \tag{C3}$$

The moment is expressed by the product of the scale reading F and the length of the moment arm (12 inches). Thus the peripheral component of the absolute rotor inlet velocity V_1 is from Eq. (C3)

$$V_{u1} = \frac{12 \, Fg}{4.75 \, \dot{W}_{vc}} \tag{C4}$$

The velocity coefficient φ is determined by an iteration using the rotor inlet velocity V_1. The first approximation of V_1 is obtained using Eq. (A37) where φ is set equal to unity. The meridional component of V_1 is then

$$V_{m1} = \sqrt{V_1^{\,2} - V_{u1}^{\,2}} \tag{C5}$$

Using the continuity equation, the density ρ_1 is

$$\rho_1 = \frac{\dot{W}_{vc}}{A_1 V_{m1}} \tag{C6}$$

[1]Vavra, M. H. <u>Aero-Thermodynamics and Flow in Turbomachines</u> (John Wiley and Sons, 1960), p. 98.

where the meridional cross-sectional area A_1 is, from Fig. 5,

$$A_1 = \frac{\pi(9.5)(0.943)}{144} \tag{C7}$$

Using the gas law, the static inlet temperature T_1 is

$$T_1 = C_f \frac{p_1}{\rho_1 R_g} \tag{C8}$$

The second approximation of V_1 is

$$V_1 = \sqrt{2gJc_p(T_{to} - T_1)} \tag{C9}$$

By reducing φ by increments of 0.0001 until the two approximations for V_1 agree within 1.0 ft/sec, the actual value of φ is obtained. The absolute rotor inlet flow angle α_1 is then

$$\alpha_1 = \tan^{-1} \frac{V_{u1}}{V_{m1}} \tag{C10}$$

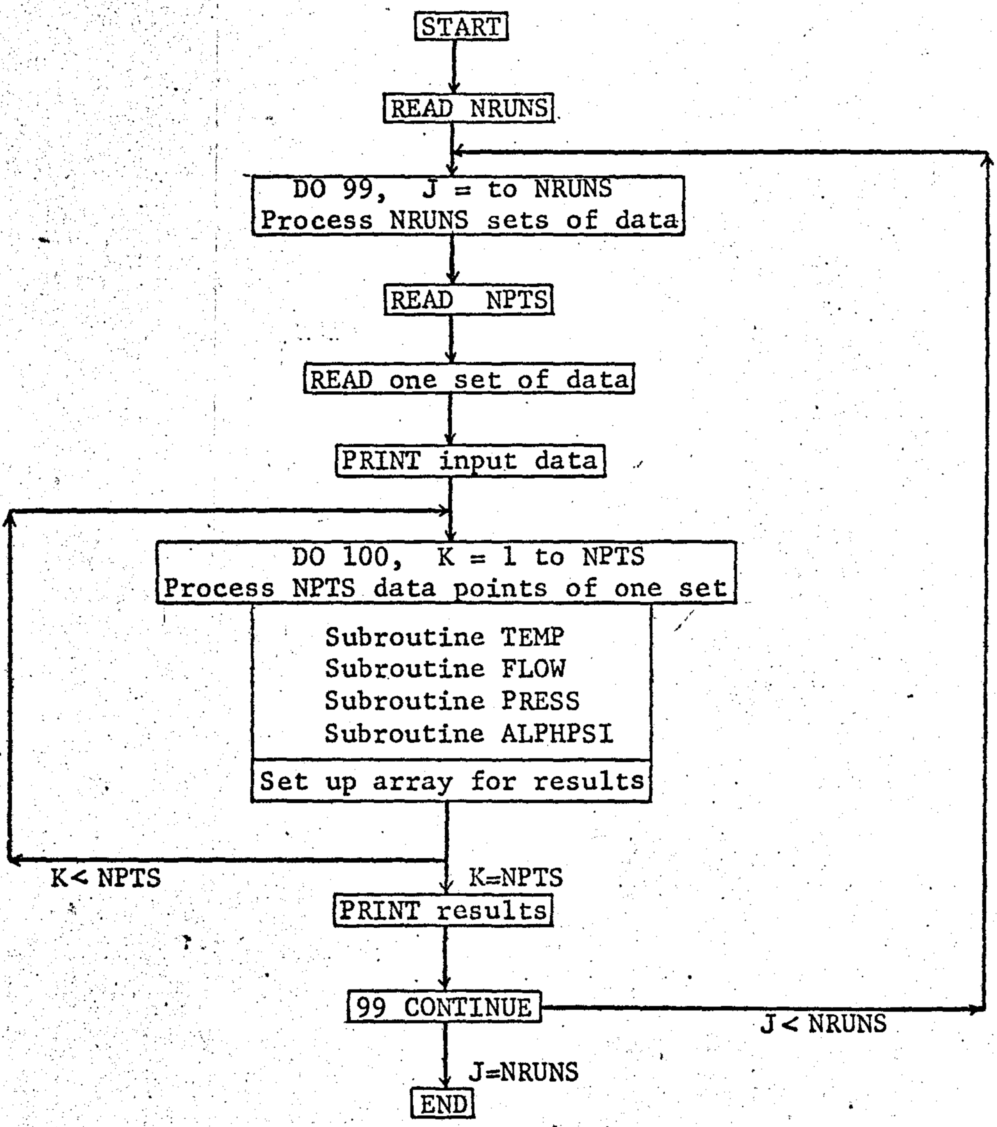

Fig. C1

Block Diagram of Program SCROLL

TABLE C1

LISTING FOR PROGRAM SCROLL

```
      PROGRAM SCROLL
      DIMENSION DPVC(10),PUVC(10),P5P(10),PATM(10),HATM(10),H1(10),
     1SR(10),TRM(10),V4(10),V5(10),WVCP(10),PRP(10),PHIP(10),ALPH(10)
      COMMON GHG,GWR,CF1,TCJ,TARE,STARE,T4,T5,WVC,PR,P1,PHI,ALP1,PAT
      READ 10,NRUNS
      DO 99 J=1,NRUNS
      READ 10,NPTS
      READ 11,(DPVC(K),PUVC(K),P5P(K),PATM(K),HATM(K),H1(K),SR(K),TRM(K)
     1,V4(K),V5(K),K=1,NPTS)
      READ 12,TCJ,TARE,STARE
      PRINT 20
      PRINT 21,(K,DPVC(K),PUVC(K),P5P(K),PATM(K),HATM(K),H1(K),SR(K),TRM
     1(K),V4(K),V5(K),K=1,NPTS)
      PRINT 24,TCJ,TARE,STARE
      DO 100 K=1,NPTS
      GHG=13.638-1.354E-3*TRM(K)
      GWR=1.00013+7.8E-5*TRM(K)-1.4E-6*TRM(K)**2
      CF1=69.892*GHG/13.59
      DPV=DPVC(K)
      PUV=PUVC(K)
      P5=P5P(K)
      PAT=PATM(K)
      HAT=HATM(K)
      P1P=H1(K)
      S=SR(K)
      V4T=V4(K)
      V5T=V5(K)
      CALL TEMP (V4T,V5T)
      CALL FLOW (DPV,PUV)
      CALL PRESS (P5,HAT,P1P)
```

```
      CALL ALPHPSI (S)
      WVCP(K)=WVC
      PRP(K)=PR
      PHIP(K)=PHI
      ALPH(K)=ALP1
  100 CONTINUE
      PRINT 22
      PRINT 23,(K,PRP(K),WVCP(K),PHIP(K),ALPH(K),K=1,NPTS)
   99 CONTINUE
      PRINT 25
   10 FORMAT(I4)
   11 FORMAT(10F7.2)
   12 FORMAT(3F7.2)
   20 FORMAT(1H1//2X14HPROGRAM SCROLL53X10HM.W. RILEY//15X49HSCROLL AND
     1GUIDE VANE TESTS OF ICP RADIAL TURBINE//27X23HTABLE        INPUT D
     2ATA /// 2X 73H  PT    DPVC    PUVC    P5P    PATM    HATM    H1    SR
     3    TRM     V4     V5/)
   21 FORMAT(I6,10F7.2)
   22 FORMAT(1H1/14HPROGRAM SCROLL35X10HM.W. RILEY//5X49HSCROLL AND GUID
     1E VANE TESTS OF ICP RADIAL TURBINE//18X24HTABLE        OUTPUT DATA
     2/// 9X39H  PT    PTO/P1    WVC       PHI    ALPH(1)/)
   23 FORMAT(I13,F8.2,2F8.3,F9.1)
   24 FORMAT(/9X5HTCJ -F6.2,6X6HTARE -F4.2,6X7HSTARE -F5.2)
   25 FORMAT(1H1)
      END
C
      SUBROUTINE TEMP (V4,V5)
      COMMON GHG,GWR,CF1,TCJ,TARE,STARE,T4,T5,WVC,PR,P1,PHI,ALP1,PAT
      V=V4
      J=1
  100 T = TCJ + 44.41 * V + .2185 * V ** 2
      IF( T - 100.) 102,102,101
  101 T = TCJ + 45.24 * V - .3295 * V ** 2
  102 T=T+459.7
      IF(J-1)103,103,104
  103 J=2
```

```
      T4=T
      V=V5
      GO TO 100
  104 T5=T
      RETURN
      END
C
      SUBROUTINE FLOW (DPVC,PUVC)
      COMMON GHG,GWR,CF1,TCJ,TARE,STARE,T4,T5,WVC,PR,P1,PHI,ALP1,PAT
      DVC=(DPVC-TARE)*GHG/13.59
      PVC=(PUVC-TARE+PAT *2.54)*GHG/13.59
      A=1.+1.E-5*(T4-530.)
      Z=1.9+2.4E-3*(T4-560.)
      Y=1.-.351*DVC/PVC
      WVC=.9057*A*Y*SQRTF(PVC*DVC/T4)
      X=WVC*.812/Z
      WVC=(1.+.00114/X)*WVC
      RETURN
      END
C
      SUBROUTINE PRESS(P5P,HAT,H1)
      COMMON GHG,GWR,CF1,TCJ,TARE,STARE,T4,T5,WVC,PR,P1,PHI,ALP1,PAT
      A=T5-459.7
      CP=.23943+3.4E-6*A+2.E-8*A**2
      P1=(PAT*GHG+(HAT-H1)*GWR)/13.59
      PS5=(PAT +(P5P-TARE)/2.54)*GHG/13.59
      TT=T5
  100 RHO=PS5*CF1/(TT*53.35)
      VO=WVC/(RHO*3.14159*6.25/144.)
      TO=T5-(VO**2)/(2.*32.174*778.16*CP)
      DTT=TT-TO
      TT=TO
      IF(ABSF(DTT)-.01)101,101,100
  101 PTO=PS5+RHO*(VO**2)/(2.*32.174*CF1)
      PR=PTO/P1
      RETURN
```

```
      END
C
      SUBROUTINE ALPHPSI (SR)
      COMMON GHG,GWR,CF1,TCJ,TARE,STARE,T4,T5,WVC,PR,P1,PHI,ALP1,PAT
      T=T5-459.7
      GAM=1.4018-2.E-5*T
      EXP=(GAM-1.)/GAM
      CP=.23943+3.4E-6*T+2.E-8*T**2
      G=2.*32.174*778.16*CP
      RM=(SR-STARE)*12.0
      VU1=RM*32.174/(WVC*4.75)
      B=T5*(1.-1./PR**EXP)
      A1=2.*3.14159*4.75*.9430/144.
      PHI=1.
  100 V1=PHI*SQRTF(G*B)
      T1=T5-(V1**2)/G
      RHO=P1*CF1/(T1*53.35)
      VM1=WVC/(A1*RHO)
      V1A=SQRTF(VM1**2+VU1**2)
      IF(ABSF(V1-V1A)-.5)102,102,101
  101 PHI=PHI-.0001
      GO TO 100
  102 ALP1=57.29578*ATANF(VU1/VM1)
      RETURN
      END
      END
```

AIR TESTS OF ICP RADIAL TURBINE

TABLE DI INPUT OF MEASURED DATA

RUN NUMBERS (CARDS 2 AND 2A)

1	1	1	1	1	1	1	1	1	0

TEST POINTS (CARDS 3 AND 3A)

1	2	3	1	2	3	1	2	3	0

UPSTREAM ORIFICE PRESSURE CM.HG (FLANGE TAPS) (CARDS 6 AND 7)

31.51	30.44	29.45	56.65	54.96	52.30	71.96	69.54	67.50	.00

UPSTREAM ORIFICE PRESSURE CM.HG (VENA CONTRACTA TAPS) (CARDS 8 AND 9)

31.47	30.30	29.49	56.14	54.54	51.94	71.54	69.00	67.01	.00

STATIC PRESSURE IN 5 IN. INLET PIPE CM.HG (CARDS 10 AND 11)

22.14	22.35	22.27	40.88	40.99	40.61	51.54	51.70	52.02	.00

ORIFICE PRESSURE DIFFERENCE CM.HG (FLANGE TAPS) (CARDS 12 AND 13)

12.99	11.47	9.88	21.68	19.16	15.90	27.79	24.27	21.09	.00

ORIFICE PRESSURE DIFFERENCE CM.HG (VENA CONTRACTA TAPS) (CARDS 14 AND 15)

12.89	11.33	10.03	21.35	18.85	15.67	27.44	23.97	20.79	.00

TURBINE SPEED RPM (CARDS 16 AND 17)

7482.	10162.	12005.	12012.	14798.	17869.	12062.	15968.	18952.	.

TORQUE SCALE READING (CARDS 18 AND 19)

25.90	20.40	15.80	44.30	34.90	24.10	60.70	46.60	35.70	.00

COLD JUNCTION TEMPERATURE DEG.F (CARDS 20 AND 21)

32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	.00

THERMOCOUPLE 4 IN. PIPE MV (CARDS 22 AND 23)

1.93	1.90	1.90	2.01	2.02	2.02	2.17	2.21	2.20	.00

THERMOCOUPLE 5 IN. PIPE MV (CARDS 24 AND 25)

1.84	1.82	1.82	1.94	1.95	1.94	2.09	2.13	2.12	.00

BAROMETER FOR EACH RUN IN.HG (CARD 30)

30.01	30.01	30.01	.00	.00	.00	.00	.00	.00	.00

CONTROL ROOM TEMPERATURE FOR EACH RUN DEG.F (CARD 31)

75.30	76.00	76.80	76.50	77.00	77.00	79.00	79.40	79.40	.00

ARE OF MICROMANOMETER CM.HG (CARD 32)

.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

AVERAGE READING OF PRESSURE AHEAD OF ROTOR IN.HG (CARDS 33 AND 34)

16.40	17.15	17.95	11.70	13.23	15.28	8.18	10.33	12.45	.00

TUBE 16 OF MANOMETER BOARD IN.HG (CARDS 35 AND 36)

23.00	23.00	23.00	23.00	23.00	23.00	23.05	23.05	23.05	.00

TABLE D1 (CONTINUED)

RUN NUMBERS										(CARDS 2 AND 2A)
	2	2	2	2	2	2	2	2	2	0
TEST POINTS										(CARDS 3 AND 3A)
	1	2	3	1	2	3	1	2	3	0
UPSTREAM ORIFICE PRESSURE CM.HG (FLANGE TAPS)										(CARDS 6 AND 7)
	35.60	34.25	32.90	62.56	60.32	57.55	79.71	76.37	74.34	.00
UPSTREAM ORIFICE PRESSURE CM.HG (VENA CONTRACTA TAPS)										(CARDS 8 AND 9)
	35.43	34.03	32.81	62.29	60.10	57.23	79.52	76.33	74.39	.00
STATIC PRESSURE IN 5 IN. INLET PIPE CM.HG										(CARDS 10 AND 11)
	22.21	22.34	22.47	40.81	40.85	41.20	52.13	51.98	52.31	.00
ORIFICE PRESSURE DIFFERENCE CM.HG (FLANGE TAPS)										(CARDS 12 AND 13)
	13.18	11.71	10.31	21.25	19.04	15.89	27.04	23.98	22.18	.00
ORIFICE PRESSURE DIFFERENCE CM.HG (VENA CONTRACTA TAPS)										(CARDS 14 AND 15)
	13.02	11.59	10.22	20.93	18.80	15.68	26.71	23.62	21.92	.00
TURBINE SPEED RPM										(CARDS 16 AND 17)
	7530.	10178.	11952.	12080.	14794.	17975.	12162.	15882.	17775.	.
TORQUE SCALE READING										(CARDS 18 AND 19)
	27.00	21.50	16.90	44.70	36.10	24.40	61.20	48.40	41.50	.00
COLD JUNCTION TEMPERATURE DEG.F										(CARDS 20 AND 21)
	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	.00
THERMOCOUPLE 4 IN. PIPE MV										(CARDS 22 AND 23)
	1.86	1.88	1.89	2.12	2.12	2.08	2.44	2.44	2.42	.00
THERMOCOUPLE 5 IN. PIPE MV										(CARDS 24 AND 25)
	1.79	1.79	1.80	2.05	2.05	2.00	2.36	2.36	2.35	.00
BAROMETER FOR EACH RUN IN.HG										(CARD 30)
	30.01	30.01	29.96	.00	.00	.00	.00	.00	.00	.00
CONTROL ROOM TEMPERATURE FOR EACH RUN DEG.F										(CARD 31)
	78.00	79.00	80.00	76.00	76.30	77.00	77.00	78.00	78.00	.00
TARE OF MICROMANOMETER CM.HG										(CARD 32)
	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
AVERAGE READING OF PRESSURE AHEAD OF ROTOR IN.H2O										(CARDS 33 AND 34)
	16.35	17.08	17.83	11.55	13.00	15.18	7.95	10.05	11.40	.00
TUBE 16 OF MANOMETER BOARD IN.HG										(CARDS 35 AND 36)
	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	.00

TABLE D1 (CONTINUED)

RUN NUMBERS									(CARDS 2 AND 2A)
3	3	3	3	3	3	3	3	3	0
TEST POINTS									(CARDS 3 AND 3A)
1	2	3	1	2	3	1	2	3	0
UPSTREAM ORIFICE PRESSURE CM.HG (FLANGE TAPS)									(CARDS 6 AND 7)
35.17	33.86	32.26	61.69	59.85	56.35	79.34	76.10	73.10	.00
UPSTREAM ORIFICE PRESSURE CM.HG (VENA CONTRACTA TAPS)									(CARDS 8 AND 9)
35.10	33.74	32.18	61.20	59.58	56.20	79.02	75.76	72.78	.00
STATIC PRESSURE IN 5 IN. INLET PIPE CM.HG									(CARDS 10 AND 11)
22.08	22.14	22.15	40.21	40.71	40.77	51.67	51.64	51.99	.00
ORIFICE PRESSURE DIFFERENCE CM.HG (FLANGE TAPS)									(CARDS 12 AND 13)
12.86	11.46	9.85	20.72	18.65	15.02	27.00	23.87	20.78	.00
ORIFICE PRESSURE DIFFERENCE CM.HG (VENA CONTRACTA TAPS)									(CARDS 14 AND 15)
12.73	11.30	9.78	20.57	18.36	14.93	26.65	23.55	20.58	.00
TURBINE SPEED RPM									(CARDS 16 AND 17)
7507.	10060.	12150.	12080.	14820.	18460.	12066.	15420.	18890.	.
TORQUE SCALE READING									(CARDS 18 AND 19)
22.70	17.50	11.90	40.10	31.40	18.90	56.20	42.30	31.10	.00
COLD JUNCTION TEMPERATURE DEG.F									(CARDS 20 AND 21)
32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	.00
THERMOCOUPLE 4 IN. PIPE MV									(CARDS 22 AND 23)
1.92	1.95	1.96	2.23	2.26	2.24	2.06	2.12	2.10	.00
THERMOCOUPLE 5 IN. PIPE MV									(CARDS 24 AND 25)
1.86	1.88	1.89	2.17	2.20	2.18	2.02	2.08	2.06	.00
BAROMETER FOR EACH RUN IN.HG									(CARD 30)
29.90	29.90	29.86	.00	.00	.00	.00	.00	.00	.00
CONTROL ROOM TEMPERATURE FOR EACH RUN DEG.F									(CARD 31)
75.00	76.00	77.00	79.00	79.20	79.80	80.50	81.00	80.20	.00
TARE OF MICROMANOMETER CM.HG									(CARD 32)
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
AVERAGE READING OF PRESSURE AHEAD OF ROTOR IN.H2O									(CARDS 33 AND 34)
16.40	17.05	18.05	11.70	13.18	15.43	8.13	10.28	12.45	.00
TUBE 16 OF MANOMETER BOARD IN.HG									(CARDS 35 AND 36)
23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	.00

TABLE D1 (CONTINUED)

Item	Cards										
RUN NUMBERS	(CARDS 2 AND 2A)	4	4	4	4	4	4	4	4	4	0
TEST POINTS	(CARDS 3 AND 3A)	1	2	3	1	2	3	1	2	3	0
UPSTREAM ORIFICE PRESSURE CM.HG (FLANGE TAPS)	(CARDS 6 AND 7)	35.72	34.13	32.72	62.36	60.23	56.99	79.38	75.90	73.31	.00
UPSTREAM ORIFICE PRESSURE CM.HG (VENA CONTRACTA TAPS)	(CARDS 8 AND 9)	35.42	33.90	32.58	62.00	59.94	56.68	79.15	75.73	72.87	.00
STATIC PRESSURE IN 5 IN. INLET PIPE CM.HG	(CARDS 10 AND 11)	22.47	22.47	22.50	41.10	41.25	41.17	52.01	52.15	51.95	.00
ORIFICE PRESSURE DIFFERENCE CM.HG (FLANGE TAPS)	(CARDS 12 AND 13)	13.03	11.50	10.07	20.93	18.70	15.50	26.79	23.50	20.63	.00
ORIFICE PRESSURE DIFFERENCE CM.HG (VENA CONTRACTA TAPS)	(CARDS 14 AND 15)	12.91	11.39	9.95	20.72	18.31	15.34	26.49	23.18	20.35	.00
TURBINE SPEED RPM	(CARDS 16 AND 17)	7535.	10144.	12064.	12053.	14824.	17800.	11960.	16050.	18860.	.
TORQUE SCALE READING	(CARDS 18 AND 19)	26.90	21.20	16.30	44.00	34.70	24.10	60.80	46.20	35.40	.00
COLD JUNCTION TEMPERATURE DEG.F	(CARDS 20 AND 21)	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	.00
THERMOCOUPLE 4 IN. PIPE MV	(CARDS 22 AND 23)	1.67	1.68	1.68	1.81	1.84	1.83	1.87	2.09	2.11	.00
THERMOCOUPLE 5 IN. PIPE MV	(CARDS 24 AND 25)	1.53	1.55	1.54	1.67	1.70	1.68	1.72	1.92	1.93	.00
BAROMETER FOR EACH RUN IN.HG	(CARD 30)	30.07	30.05	30.04	.00	.00	.00	.00	.00	.00	.00
CONTROL ROOM TEMPERATURE FOR EACH RUN DEG.F	(CARD 31)	77.00	77.00	77.50	78.00	78.50	79.00	79.20	79.20	79.00	.00
TARE OF MICROMANOMETER CM.HG	(CARD 32)	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
AVERAGE READING OF PRESSURE AHEAD OF ROTOR IN.H2O	(CARDS 33 AND 34)	16.29	17.04	17.92	11.59	13.12	15.06	8.00	10.28	12.40	.00
TUBE 16 OF MANOMETER BOARD IN.HG	(CARDS 35 AND 36)	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	.00

TABLE D1 (CONTINUED)

RUN NUMBERS (CARDS 2 AND 2A)

5	5	5	5	5	5	5	5	5	5

TEST POINTS (CARDS 3 AND 3A)

1	2	3	1	2	3	4	1	2	3

UPSTREAM ORIFICE PRESSURE CM.HG (FLANGE TAPS) (CARDS 6 AND 7)

35.53	33.70	32.57	61.89	59.72	59.34	56.05	79.44	76.88	72.96

UPSTREAM ORIFICE PRESSURE CM.HG (VENA CONTRACTA TAPS) (CARDS 8 AND 9)

35.28	32.25	32.50	61.48	59.43	58.71	55.99	79.15	76.29	72.34

STATIC PRESSURE IN 5 IN. INLET PIPE CM.HG (CARDS 10 AND 11)

22.44	22.21	22.52	40.89	40.73	40.85	41.00	52.00	51.80	51.85

ORIFICE PRESSURE DIFFERENCE CM.HG (FLANGE TAPS) (CARDS 12 AND 13)

12.77	11.25	9.95	20.59	18.55	17.81	14.82	26.75	24.02	20.09

ORIFICE PRESSURE DIFFERENCE CM.HG (VENA CONTRACTA TAPS) (CARDS 14 AND 15)

12.59	11.14	9.82	20.28	18.27	17.56	14.52	26.31	23.60	19.73

TURBINE SPEED RPM (CARDS 16 AND 17)

7510.	10145.	12120.	12100.	14730.	15414.	18520.	12066.	15500.	19330.

TORQUE SCALE READING (CARDS 18 AND 19)

27.50	21.20	16.50	44.00	35.70	33.20	22.50	61.00	48.60	34.00

COLD JUNCTION TEMPERATURE DEG.F (CARDS 20 AND 21)

32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00

THERMOCOUPLE 4 IN. PIPE MV (CARDS 22 AND 23)

2.03	2.04	2.04	2.27	2.23	2.24	2.22	2.23	2.26	2.25

THERMOCOUPLE 5 IN. PIPE MV (CARDS 24 AND 25)

1.91	1.91	1.91	2.15	2.11	2.12	2.10	2.12	2.14	2.14

BAROMETER FOR EACH RUN IN.HG (CARD 30)

30.05	30.04	30.04	.00	.00	.00	.00	.00	.00	.00

CONTROL ROOM TEMPERATURE FOR EACH RUN DEG.F (CARD 31)

79.00	79.80	80.00	81.00	81.00	81.00	81.00	81.30	81.30	.00

TARE OF MICROMANOMETER CM.HG (CARD 32)

.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

AVERAGE READING OF PRESSURE AHEAD OF ROTOR IN.H2O (CARDS 33 AND 34)

16.25	17.13	17.85	11.62	13.13	13.57	15.48	7.96	9.88	12.64

TUBE 16 OF MANOMETER BOARD IN.HG (CARDS 35 AND 36)

22.99	22.99	22.98	22.99	22.98	22.98	22.99	23.00	23.00	23.00

AIR TESTS OF ICP RADIAL TURBINE

TABLE D2 MEASURED DATA

RUN 1 CLEARANCE - .027 PRESSURE RATIO - 1.30

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
10162.	.00	30.30	11.33	23.00	17.15	17.15	22.35	30.01	76.0	1.90	1.82	32.0	20.4

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	37.5	38.8	41.9	43.2	40.7	39.9	-5.6	.00
1.82	37.4	38.9	41.7	43.3	40.6	40.0	-7.2	.00
1.90	37.2	39.1	41.4	43.6	40.4	40.2	-7.6	.00
2.10	37.0	39.3	41.0	43.9	40.1	40.5	4.2	.00
2.34	37.1	39.2	40.9	44.0	40.1	40.5	22.2	.00
2.60	37.1	39.2	40.6	44.3	40.4	40.2	38.2	.00
2.80	34.1	42.4	37.6	46.8	41.8	38.7	46.4	.00
2.88	32.4	44.1	36.2	48.1	40.9	39.7	42.2	.00
2.92	31.6	45.0	35.5	48.7	39.6	41.1	43.2	.00
1.78	58.4	59.5	52.0	53.7	53.1	52.2	-3.4	.00
1.82	58.2	59.7	51.8	53.8	53.0	52.3	-6.6	.00
1.90	58.0	59.9	52.1	54.1	52.7	52.6	-6.4	.00
2.10	57.8	60.0	51.3	54.3	52.4	53.1	.2	.00
2.34	58.1	59.8	51.3	54.3	52.3	53.1	19.0	.00
2.60	58.1	59.8	51.0	54.7	52.5	52.8	38.0	.00
2.80	55.2	62.6	46.5	57.2	53.2	52.0	42.8	.00
2.88	53.4	64.3	47.3	58.5	52.1	53.3	40.0	.00
2.92	52.6	65.0	46.8	58.8	51.1	54.5	38.8	.00

RUN 1 CLEARANCE - .027 PRESSURE RATIO - 1.55

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
17869.	.00	51.94	15.67	23.00	15.30	15.25	40.61	30.01	77.0	2.02	1.94	32.0	24.1

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	39.3	40.3	40.5	42.8	38.3	36.7	70.2	.00
1.82	38.6	41.1	40.0	43.4	38.5	36.5	62.2	.00
1.90	37.3	42.5	38.6	45.0	38.5	36.5	55.6	.00
2.10	32.7	47.2	34.1	50.0	37.1	37.8	53.8	.00
2.34	30.5	49.3	32.4	51.8	36.2	38.6	57.0	.00
2.60	29.9	50.0	32.0	52.3	37.3	37.6	57.2	.00
2.80	21.5	58.2	25.7	59.3	40.6	34.5	52.0	.00
2.88	16.1	63.5	21.8	63.5	38.1	36.8	48.0	.00
2.92	13.1	66.0	20.4	65.0	34.6	39.9	46.8	.00
1.78	52.3	50.9	51.4	52.5	58.4	58.0	90.0	.00
1.82	52.3	51.0	51.3	52.5	58.5	57.9	88.0	.00
1.90	51.6	51.8	50.9	53.0	58.7	57.7	61.8	.00
2.10	48.5	55.6	47.5	56.6	58.0	58.3	51.0	.00
2.34	44.7	60.0	44.0	60.1	56.4	59.9	51.0	.00
2.60	42.6	62.4	41.9	62.2	56.7	59.6	51.0	.00
2.80	37.2	68.6	37.2	66.8	57.3	59.0	46.8	.00
2.88	33.6	72.7	34.6	69.2	55.0	61.1	44.0	.00
2.92	32.3	74.2	34.1	69.8	52.8	63.2	42.6	.00

RUN 1 CLEARANCE - .027 PRESSURE RATIO - 1.70

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
18952.	.00	67.01	20.79	23.05	12.50	12.40	52.02	30.01	79.4	2.20	2.12	32.0	35.7

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	36.9	42.9	38.2	45.4	38.7	36.3	56.4	.00
1.82	35.8	43.9	37.2	46.5	38.5	36.5	54.0	.00
1.90	34.5	45.4	35.8	48.1	38.1	37.0	52.8	.00
2.10	31.8	48.2	33.3	50.9	37.1	37.8	52.8	.00
2.34	31.2	48.7	32.7	51.5	36.7	38.2	50.2	.00
2.60	31.3	48.6	32.4	51.9	37.3	37.6	51.0	.00
2.80	20.6	59.1	24.1	60.9	42.5	32.7	50.0	.00
2.88	15.2	64.5	20.1	65.4	39.5	35.5	46.2	.00
2.92	11.9	67.6	18.3	67.2	35.2	39.4	35.0	.00
1.78	50.6	53.1	50.2	53.7	59.2	57.2	57.2	.00
1.82	49.7	54.1	49.3	54.6	59.0	57.3	53.2	.00
1.90	48.2	55.8	47.8	56.1	58.5	57.8	49.8	.00
2.10	45.2	59.3	45.0	58.9	57.0	59.3	47.4	.00
2.34	43.6	61.1	43.3	60.6	56.4	59.8	48.0	.00
2.60	42.5	62.3	41.7	62.2	56.8	59.4	49.0	.00
2.80	36.4	69.3	36.0	67.8	58.3	57.9	46.0	.00
2.88	31.8	74.5	32.6	71.0	55.7	60.3	42.6	.00
2.92	29.9	76.8	31.6	72.0	53.0	62.8	40.4	.00

TABLE D2 (CONTINUED)

RUN 2 CLEARANCE - .042 PRESSURE RATIO - 1.30

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
7530.	.00	35.43	13.02	23.00	16.35	16.35	22.21	30.01	78.0	1.86	1.79	32.0	27.0

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	35.3	44.4	36.8	46.7	39.5	35.3	-46.0	.00
1.82	34.0	45.6	35.8	48.0	38.7	36.1	-45.6	.00
1.90	32.9	46.8	34.8	49.0	37.3	37.3	-45.0	.00
2.10	33.6	46.0	35.8	47.9	35.4	39.1	-43.4	.00
2.34	36.8	42.7	38.4	45.0	35.9	38.7	-36.4	.00
2.60	39.0	40.5	40.0	43.2	36.7	38.0	-12.6	.00
2.80	38.2	41.3	39.3	44.0	38.5	36.2	30.2	.00
2.88	37.2	42.4	38.5	44.8	38.0	36.7	33.4	.00
2.92	36.8	42.8	38.4	45.0	37.3	37.5	34.8	.00
1.78	47.1	56.2	47.1	55.9	59.9	55.5	-49.0	.00
1.82	46.3	57.3	46.4	56.7	59.4	56.1	-47.2	.00
1.90	45.1	58.5	45.4	57.7	58.2	57.2	-46.2	.00
2.10	45.5	58.1	46.0	57.1	56.6	58.8	-45.4	.00
2.34	48.1	55.0	48.2	54.8	56.8	58.7	-40.4	.00
2.60	50.2	52.6	49.8	53.2	57.2	58.2	-22.2	.00
2.80	50.0	53.0	49.7	53.3	58.5	57.0	19.2	.00
2.88	49.1	54.0	49.0	54.1	58.0	57.5	23.6	.00
2.92	48.8	54.3	48.6	54.4	57.4	58.1	23.6	.00

RUN 2 CLEARANCE - .042 PRESSURE RATIO - 1.30

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
10178.	.00	34.03	11.59	23.00	17.10	17.05	22.34	30.01	79.0	1.88	1.79	32.0	21.5

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	39.0	40.6	40.7	42.5	37.8	37.0	-13.4	.00
1.82	39.0	40.6	40.5	42.7	37.6	37.1	-12.0	.00
1.90	38.8	40.8	40.3	43.0	37.4	37.3	-10.4	.00
2.10	38.6	41.0	39.9	43.4	37.2	37.5	-.2	.00
2.34	38.7	40.9	39.8	43.5	37.2	37.5	18.4	.00
2.60	38.9	40.8	39.8	43.6	37.5	37.3	40.0	.00
2.80	35.6	44.1	37.0	46.6	39.7	35.2	45.8	.00
2.88	33.4	46.3	35.4	48.5	38.9	35.9	44.4	.00
2.92	31.7	48.1	34.1	49.8	37.1	37.5	42.0	.00
1.78	50.6	52.2	50.7	52.4	58.5	57.1	-8.6	.00
1.82	50.5	52.3	50.7	52.3	58.3	57.2	-8.0	.00
1.90	50.3	52.6	50.4	52.7	58.1	57.5	-8.0	.00
2.10	50.2	52.7	50.2	52.9	57.7	57.8	-2.0	.00
2.34	50.4	52.4	50.2	53.0	57.6	57.9	15.4	.00
2.60	50.7	52.2	50.0	53.1	57.9	57.7	38.0	.00
2.80	48.0	55.4	47.5	55.3	59.2	56.4	43.2	.00
2.88	45.6	58.1	45.5	57.7	58.4	57.1	43.0	.00
2.92	44.1	59.8	44.5	58.7	57.0	58.5	42.2	.00

RUN 2 CLEARANCE - .042 PRESSURE RATIO - 1.30

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
11952.	.00	32.81	10.22	23.00	17.85	17.80	22.47	30.01	80.0	1.89	1.80	32.0	16.9

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	39.0	40.5	40.6	42.7	37.6	37.1	47.4	.00
1.82	38.9	40.7	40.4	42.9	37.6	37.2	45.8	.00
1.90	38.5	41.1	40.0	43.3	37.5	37.3	45.8	.00
2.10	37.8	41.8	39.3	44.2	37.4	37.4	46.4	.00
2.34	37.0	42.6	38.5	45.0	37.2	37.6	50.6	.00
2.60	36.6	43.0	38.1	45.4	37.3	37.4	59.4	.00
2.80	32.7	47.1	34.9	49.0	40.1	34.8	49.6	.00
2.88	29.2	50.5	32.3	51.7	39.1	35.7	44.8	.00
2.92	26.4	53.4	30.5	53.9	36.7	37.3	44.0	.00
1.78	50.7	52.1	50.7	52.4	58.0	57.6	51.2	.00
1.82	50.5	52.4	50.6	52.5	58.0	57.6	48.0	.00
1.90	50.1	52.8	50.2	52.9	57.8	57.8	46.4	.00
2.10	49.5	53.6	49.6	53.6	57.4	58.1	44.0	.00
2.34	48.9	54.2	48.9	54.3	57.2	58.4	47.4	.00
2.60	48.5	54.8	48.3	54.9	57.3	58.3	52.8	.00
2.80	46.0	57.7	45.8	57.4	58.8	56.8	46.4	.00
2.88	42.5	61.6	43.0	60.0	58.3	57.2	42.0	.00
2.92	41.3	64.2	41.5	61.7	56.5	58.9	42.0	.00

TABLE D2 (CONTINUED)

RUN 2 CLEARANCE - .042 PRESSURE RATIO - 1.55

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
12080.	.00	62.29	20.93	23.00	11.60	11.50	43.81	30.01	76.0	2.12	2.05	32.0	44.7

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	37.3	42.3	38.6	44.9	38.4	36.6	-35.0	.00
1.82	36.8	42.7	37.8	45.6	37.9	36.9	-32.6	.00
1.90	36.6	43.0	37.5	46.0	37.4	37.4	-32.6	.00
2.10	37.0	42.6	37.7	45.8	36.7	38.0	-25.2	.00
2.34	38.8	40.7	38.9	44.5	36.6	38.0	-10.0	.00
2.60	40.0	39.5	39.4	44.0	37.7	37.1	16.0	.00
2.80	34.6	45.0	35.3	48.4	41.1	33.8	36.0	.00
2.88	31.8	47.7	33.6	50.4	39.1	35.7	36.0	.00
2.92	30.7	49.0	33.1	51.0	37.0	37.7	36.4	.00
1.78	48.4	54.8	48.4	54.8	58.7	57.0	-40.4	.00
1.82	48.4	54.9	48.1	55.1	58.5	57.2	-36.6	.00
1.90	48.4	54.9	48.0	55.2	58.2	57.6	-34.4	.00
2.10	49.0	54.2	48.3	55.0	57.6	58.1	-26.4	.00
2.34	50.6	52.2	49.4	53.8	57.4	58.2	-11.0	.00
2.60	51.6	51.2	49.8	53.4	58.0	57.8	21.8	.00
2.80	47.7	55.8	46.0	57.4	60.5	55.3	31.8	.00
2.88	44.6	59.4	43.4	60.0	58.8	56.8	32.4	.00
2.92	42.9	61.3	42.3	61.0	56.8	58.9	32.4	.00

RUN 2 CLEARANCE - .042 PRESSURE RATIO - 1.55

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
14794.	.00	60.10	18.80	23.00	13.05	12.95	40.85	30.01	76.3	2.12	2.05	32.0	36.1

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	38.8	40.9	39.6	43.8	38.0	36.8	20.0	.00
1.82	38.5	41.1	39.4	44.0	37.8	37.0	18.0	.00
1.90	38.5	41.1	39.3	44.1	37.7	37.1	18.0	.00
2.10	37.9	41.8	38.5	45.0	38.0	36.9	26.4	.00
2.34	37.5	42.3	38.0	45.6	37.5	37.4	37.2	.00
2.60	37.9	41.8	38.0	45.6	37.5	37.4	45.4	.00
2.80	30.8	49.0	32.1	52.1	43.4	31.6	37.8	.00
2.88	23.0	56.5	26.6	58.1	41.0	33.9	37.8	.00
2.92	19.1	60.5	24.0	61.1	37.0	37.8	38.4	.00
1.78	49.9	53.1	49.7	53.5	58.4	57.3	31.8	.00
1.82	49.7	53.2	49.6	53.5	58.3	57.4	26.6	.00
1.90	49.7	53.2	49.3	53.8	58.1	57.6	22.4	.00
2.10	49.1	54.1	48.4	54.2	57.8	57.8	24.0	.00
2.34	48.9	54.2	47.9	55.3	57.4	58.3	37.8	.00
2.60	48.9	54.2	47.5	55.7	57.6	58.1	46.6	.00
2.80	44.3	59.6	42.8	60.4	60.5	55.2	36.4	.00
2.88	38.8	65.8	38.4	64.8	59.5	56.1	35.0	.00
2.92	35.0	70.4	35.3	67.8	56.2	59.3	35.6	.00

RUN 2 CLEARANCE - .042 PRESSURE RATIO - 1.55

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
17972.	.00	57.23	15.68	23.00	15.20	15.15	41.20	30.01	77.0	2.08	2.00	32.0	24.4

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	39.0	40.5	40.4	43.0	38.3	36.6	68.4	.00
1.82	38.4	41.1	39.8	43.6	38.3	36.6	60.2	.00
1.90	37.0	42.7	38.2	45.3	38.2	36.7	54.8	.00
2.10	32.7	47.0	34.2	49.8	36.8	37.9	54.0	.00
2.34	30.5	49.2	32.6	51.6	36.1	38.5	57.2	.00
2.60	29.7	50.0	31.9	52.4	36.9	37.9	58.6	.00
2.80	21.1	58.5	25.5	59.5	40.7	34.2	54.2	.00
2.88	14.9	64.6	21.1	64.1	38.2	36.4	49.6	.00
2.92	11.9	67.6	19.5	66.0	35.0	39.4	47.6	.00
1.78	52.3	50.2	51.1	52.0	58.2	57.5	90.2	.00
1.82	52.1	50.4	51.0	52.1	58.3	57.5	78.0	.00
1.90	51.3	51.3	50.1	53.0	58.4	57.4	58.6	.00
2.10	48.0	54.6	46.8	56.3	57.4	58.3	49.4	.00
2.34	44.7	59.0	43.8	59.4	56.0	59.6	51.4	.00
2.60	43.1	60.8	42.0	61.1	56.3	59.3	52.4	.00
2.80	37.1	66.9	36.5	66.6	58.0	57.6	48.6	.00
2.88	32.7	72.3	33.3	69.7	56.0	59.5	45.4	.00
2.92	30.5	75.4	32.2	70.7	53.5	61.9	43.4	.00

TABLE D2 (CONTINUED)

RUN 2 CLEARANCE - .042 PRESSURE RATIO - 1.70

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
12162.	.00	79.52	26.71	23.00	7.95	7.95	52.13	29.96	77.0	2.44	2.36	32.0	61.2

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	29.6	49.8	31.3	52.6	40.5	34.2	-44.0	.00
1.82	28.3	51.2	30.2	53.9	39.0	35.6	-43.6	.00
1.90	27.5	52.0	29.2	54.5	36.9	37.6	-43.4	.00
2.10	30.7	48.7	32.6	51.3	34.5	39.8	-40.8	.00
2.34	35.6	43.9	36.3	47.1	34.5	39.7	-33.8	.00
2.60	39.4	39.9	39.2	44.0	36.8	37.6	-12.4	.00
2.80	34.9	44.6	35.2	48.5	41.7	33.6	20.8	.00
2.88	31.1	48.4	32.6	51.2	40.0	34.8	21.0	.00
2.92	29.5	50.0	31.6	52.4	37.0	37.5	21.0	.00
1.78	40.5	63.6	40.9	62.1	60.5	55.1	-46.4	.00
1.82	39.8	64.5	40.2	62.9	59.4	56.1	-46.0	.00
1.90	39.6	64.7	40.0	63.0	57.7	57.7	-45.0	.00
2.10	42.0	62.0	42.1	60.9	56.0	59.6	-42.2	.00
2.34	46.7	56.7	45.9	57.2	55.7	59.9	-36.8	.00
2.60	50.8	51.9	49.0	54.1	57.8	57.8	-19.2	.00
2.80	46.5	57.0	45.5	57.7	61.1	54.6	19.6	.00
2.88	43.5	60.5	43.2	60.0	58.9	56.6	19.0	.00
2.92	42.5	61.6	42.5	60.8	57.1	58.6	18.0	.00

RUN 2 CLEARANCE - .042 PRESSURE RATIO - 1.70

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
15882.	.00	76.33	23.62	23.00	10.10	10.00	51.98	29.96	78.0	2.44	2.36	32.0	48.4

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	38.3	41.4	38.6	44.8	38.5	36.3	3.4	.00
1.82	38.2	41.5	38.5	44.9	38.3	36.6	3.0	.00
1.90	38.1	41.6	38.5	45.0	38.0	36.8	3.6	.00
2.10	38.0	41.7	38.2	45.3	37.7	37.1	11.4	.00
2.34	38.3	41.4	38.2	45.4	37.4	37.4	26.6	.00
2.60	38.4	41.3	38.0	45.6	37.8	37.0	35.8	.00
2.80	30.2	49.3	31.0	53.5	44.7	30.5	31.2	.00
2.88	19.0	60.6	23.1	62.0	40.2	34.5	35.0	.00
2.92	16.1	63.4	21.2	64.0	37.0	37.5	35.8	.00
1.78	49.9	53.0	49.1	54.0	59.0	56.7	8.8	.00
1.82	49.6	53.2	48.8	54.2	58.8	56.9	4.6	.00
1.90	49.4	53.5	48.5	54.5	58.6	57.1	3.6	.00
2.10	49.3	53.6	48.0	55.1	57.9	57.7	13.6	.00
2.34	50.1	52.8	48.3	54.8	57.7	58.0	30.4	.00
2.60	50.1	52.8	47.9	55.2	58.0	57.7	38.6	.00
2.80	44.1	59.7	41.8	61.3	61.2	54.3	30.0	.00
2.88	37.2	67.6	36.1	67.0	60.0	55.5	31.8	.00
2.92	32.8	72.8	33.0	70.0	56.0	59.4	32.8	.00

RUN 2 CLEARANCE - .042 PRESSURE RATIO - 1.70

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
17775.	.00	74.39	21.92	23.00	11.45	11.35	52.31	29.93	78.0	2.42	2.35	32.0	41.5

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	36.8	42.9	38.0	45.5	38.0	36.7	46.8	.00
1.82	36.6	43.0	37.9	45.7	37.7	37.0	44.6	.00
1.90	36.6	43.0	37.8	45.8	37.5	37.2	44.0	.00
2.10	36.2	43.4	37.1	46.6	37.5	37.2	40.2	.00
2.34	35.4	44.3	35.9	48.0	37.1	37.6	37.0	.00
2.60	35.4	44.3	35.4	48.4	37.3	37.4	45.0	.00
2.80	26.0	53.6	28.0	56.7	44.5	30.6	44.0	.00
2.88	17.3	62.3	21.6	63.7	43.3	31.6	41.6	.00
2.92	10.6	68.7	17.2	68.3	37.0	37.5	41.0	.00
1.78	48.3	54.7	48.2	54.7	58.3	57.3	49.0	.00
1.82	47.8	55.3	47.8	55.3	58.0	57.6	46.6	.00
1.90	47.3	55.9	47.1	55.8	57.5	58.1	45.0	.00
2.10	46.9	56.4	46.6	56.4	57.1	58.4	42.0	.00
2.34	46.0	57.3	45.4	57.6	56.9	58.7	41.8	.00
2.60	45.8	57.6	44.7	58.3	56.7	58.8	42.4	.00
2.80	40.3	63.9	39.0	63.9	60.0	55.5	42.0	.00
2.88	33.5	71.9	33.2	69.6	58.6	56.7	39.4	.00
2.92	28.9	77.3	29.9	72.8	55.1	60.0	38.6	.00

TABLE D2 (CONTINUED)

RUN 3 CLEARANCE - .057 PRESSURE RATIO - 1.30

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
7507.	.00	35.10	12.73	23.00	16.40	16.40	22.08	29.90	75.0	1.92	1.86	32.0	22.7

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	35.7	42.7	37.1	45.1	38.5	34.6	-47.6	.00
1.82	34.7	43.8	36.2	46.1	38.0	35.1	-45.4	.00
1.90	33.4	45.1	35.1	47.9	36.8	36.2	-44.0	.00
2.10	33.7	44.7	35.6	46.7	35.2	37.6	-40.0	.00
2.34	36.5	41.9	38.0	44.1	35.2	37.6	-32.8	.00
2.60	38.9	39.4	39.9	42.0	36.0	36.9	-10.6	.00
2.80	37.0	41.4	38.2	44.0	38.5	34.6	37.2	.00
2.88	35.6	42.8	37.2	45.0	37.7	35.3	37.4	.00
2.92	35.0	43.4	36.7	45.6	36.7	36.3	37.6	.00
1.78	46.4	54.4	46.2	54.4	58.5	54.5	-48.4	.00
1.82	45.4	55.5	45.5	55.2	57.9	55.1	-46.8	.00
1.90	44.4	56.7	44.6	56.1	56.8	56.1	-44.4	.00
2.10	44.5	56.6	45.0	55.7	55.2	57.8	-43.2	.00
2.34	47.0	53.7	47.0	53.5	55.4	57.6	-38.0	.00
2.60	49.0	51.3	48.6	52.0	56.0	57.0	-18.8	.00
2.80	48.4	52.5	48.0	52.6	57.5	55.6	27.0	.00
2.88	47.2	53.3	47.1	53.5	56.8	56.3	30.6	.00
2.92	46.8	53.8	46.7	53.8	56.2	56.8	31.4	.00

RUN 3 CLEARANCE - .057 PRESSURE RATIO - 1.30

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
10060.	.00	33.74	11.30	23.00	17.05	17.05	22.14	29.90	76.0	1.95	1.88	32.0	17.5

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	38.5	39.8	40.1	41.9	37.0	36.0	-21.6	.00
1.82	38.3	40.1	39.9	42.1	36.8	36.1	-17.6	.00
1.90	38.1	40.3	39.5	42.4	36.6	36.4	-16.0	.00
2.10	38.0	40.4	39.2	42.8	36.4	36.6	-3.8	.00
2.34	38.0	40.3	39.2	42.8	36.4	36.6	17.2	.00
2.60	38.0	40.3	39.0	43.2	36.7	36.3	40.2	.00
2.80	34.7	43.8	36.1	46.3	39.0	34.1	47.4	.00
2.88	32.4	46.1	34.4	48.3	38.3	34.8	46.4	.00
2.92	30.6	47.9	33.1	49.6	36.7	36.2	46.4	.00
1.78	49.3	51.0	49.4	51.0	57.2	55.9	-11.0	.00
1.82	49.1	51.2	49.3	51.3	57.1	56.0	-11.0	.00
1.90	48.9	51.5	49.0	51.5	56.8	56.3	-10.0	.00
2.10	48.8	51.6	48.9	51.7	56.4	56.8	-5.0	.00
2.34	49.1	51.2	49.0	51.5	56.3	56.9	12.6	.00
2.60	49.3	51.0	48.6	52.0	56.5	56.6	35.2	.00
2.80	47.1	53.6	46.4	54.3	57.7	55.5	45.2	.00
2.88	44.6	56.5	44.5	56.3	57.1	56.0	45.6	.00
2.92	42.9	58.5	43.3	57.3	55.6	57.4	45.8	.00

RUN 3 CLEARANCE - .057 PRESSURE RATIO - 1.30

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
12150.	.00	32.18	9.78	23.00	18.05	18.05	22.15	29.90	77.0	1.96	1.89	32.0	11.9

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	38.7	39.7	40.2	41.8	36.8	36.3	55.6	.00
1.82	38.4	40.0	40.0	42.0	36.7	36.3	52.0	.00
1.90	38.0	40.4	39.5	42.5	36.6	36.4	50.2	.00
2.10	37.1	41.4	38.5	43.5	36.4	36.6	53.4	.00
2.34	36.2	42.2	37.9	44.3	36.3	36.7	55.4	.00
2.60	35.4	43.0	37.1	45.2	36.6	36.4	59.2	.00
2.80	31.5	47.0	34.1	48.6	39.3	33.9	51.0	.00
2.88	27.6	50.1	31.2	51.7	39.0	34.0	47.0	.00
2.92	24.5	54.1	29.1	54.1	36.7	36.3	46.2	.00
1.78	49.9	50.3	49.9	50.7	56.9	56.3	67.4	.00
1.82	49.8	50.5	49.9	50.7	56.9	56.3	58.2	.00
1.90	49.4	51.0	49.4	51.1	56.8	56.3	48.8	.00
2.10	48.3	52.2	48.3	52.3	56.2	56.9	48.2	.00
2.34	47.3	53.3	47.4	53.2	55.8	57.3	51.0	.00
2.60	46.6	54.1	46.6	54.0	55.8	57.3	54.6	.00
2.80	44.4	56.7	44.5	56.2	57.0	56.0	49.6	.00
2.88	41.1	60.5	41.8	58.9	56.6	56.4	46.0	.00
2.92	38.7	63.3	40.1	60.5	55.0	58.0	45.0	.00

TABLE D2 (CONTINUED)

RUN 3 CLEARANCE - .057 PRESSURE RATIO - 1.55

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
12080.	.00	61.20	20.57	23.00	11.70	11.70	40.21	29.90	79.0	2.23	2.17	32.0	40.1

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	37.0	41.5	38.3	44.0	37.4	35.7	-38.4	.00
1.82	36.5	42.0	37.8	44.5	37.2	36.0	-32.8	.00
1.90	36.1	42.4	37.1	45.3	36.6	36.4	-32.4	.00
2.10	36.2	42.3	37.0	45.4	36.0	37.0	-24.0	.00
2.34	37.6	40.8	37.9	44.4	36.0	37.0	-6.2	.00
2.60	39.1	39.3	38.6	43.7	36.6	36.4	23.6	.00
2.80	33.6	45.0	33.9	49.0	40.7	32.6	43.0	.00
2.88	30.6	47.9	31.6	51.4	38.8	34.2	42.2	.00
2.92	28.7	49.9	30.4	52.8	36.5	36.5	42.4	.00
1.78	47.8	52.8	47.1	53.5	57.7	55.5	-35.2	.00
1.82	47.5	53.2	47.0	53.7	57.4	55.8	-33.2	.00
1.90	47.2	53.4	46.7	54.0	56.8	56.2	-31.6	.00
2.10	47.6	53.0	46.8	53.9	55.1	57.1	-23.6	.00
2.34	49.0	51.4	47.5	53.1	56.0	57.2	-1.0	.00
2.60	50.1	50.1	48.0	52.7	56.4	56.8	19.0	.00
2.80	46.3	54.5	44.2	56.5	58.9	54.3	38.0	.00
2.88	42.9	58.4	41.5	59.1	57.3	55.8	38.6	.00
2.92	41.4	60.3	40.5	60.2	55.2	57.7	38.2	.00

RUN 3 CLEARANCE - .057 PRESSURE RATIO - 1.55

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
14820.	.00	59.58	18.36	23.00	13.20	13.15	40.71	29.90	79.2	2.26	2.20	32.0	31.4

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	38.2	40.3	39.4	42.8	37.1	36.0	24.0	.00
1.82	38.0	40.5	39.2	43.0	36.9	36.2	23.2	.00
1.90	37.8	40.7	38.8	43.4	36.8	36.3	22.0	.00
2.10	36.7	41.6	37.8	44.5	37.0	36.0	30.0	.00
2.34	36.5	41.8	37.2	45.2	36.6	36.5	40.2	.00
2.60	36.4	42.0	36.9	45.5	37.0	36.1	50.2	.00
2.80	29.5	49.0	31.2	51.9	42.7	30.7	40.4	.00
2.88	22.5	56.0	26.0	57.6	42.1	31.1	40.0	.00
2.92	17.2	61.2	22.4	61.5	37.2	35.7	40.4	.00
1.78	48.4	52.1	48.3	52.3	56.9	56.3	40.8	.00
1.82	48.4	52.1	48.3	52.3	56.8	56.4	36.4	.00
1.90	48.2	52.3	48.1	52.5	56.7	56.5	32.0	.00
2.10	47.7	52.9	47.3	53.4	56.4	56.9	30.2	.00
2.34	47.3	53.4	46.4	54.3	55.9	57.3	42.6	.00
2.60	47.0	53.7	45.9	54.9	56.0	57.0	52.0	.00
2.80	43.0	58.5	41.9	58.9	58.5	54.7	42.0	.00
2.88	37.6	64.5	37.5	63.2	57.6	55.3	39.4	.00
2.92	33.8	69.2	34.7	65.9	54.4	58.5	39.4	.00

RUN 3 CLEARANCE - .057 PRESSURE RATIO - 1.55

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
16460.	.00	56.20	14.93	23.00	15.45	15.40	40.77	29.90	79.8	2.24	2.18	32.0	18.9

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	39.2	39.2	40.4	41.7	37.0	36.1	90.0	.00
1.82	39.1	39.3	40.4	41.7	37.0	36.0	83.0	.00
1.90	38.1	40.3	39.9	42.3	37.5	35.7	65.8	.00
2.10	34.5	44.0	35.8	46.8	37.3	35.8	50.2	.00
2.34	29.2	49.4	30.9	52.3	35.9	37.1	54.2	.00
2.60	27.6	50.9	29.8	53.4	36.3	36.6	58.2	.00
2.80	17.6	60.7	22.5	61.4	41.6	31.6	54.0	.00
2.88	10.8	67.4	17.7	66.6	39.5	33.6	50.0	.00
2.92	6.6	71.5	15.3	69.4	36.0	36.8	48.0	.00
1.78	50.5	49.6	50.2	50.5	56.7	56.5	90.0	.00
1.82	50.5	49.6	50.2	50.5	56.7	56.5	90.0	.00
1.90	50.5	49.6	50.2	50.5	57.0	56.3	70.0	.00
2.10	48.1	52.4	47.8	52.8	57.2	56.1	52.2	.00
2.34	42.9	58.5	42.5	58.1	55.3	57.9	50.4	.00
2.60	39.8	62.0	39.7	61.0	54.5	58.6	53.8	.00
2.80	33.7	69.1	34.1	66.5	56.2	56.8	51.4	.00
2.88	28.5	75.0	30.3	70.1	54.1	58.8	48.8	.00
2.92	25.8	78.1	28.7	71.7	51.3	61.5	47.0	.00

TABLE D2 (CONTINUED)

RUN 3 CLEARANCE - .057 PRESSURE RATIO - 1.70

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
12066.	.00	79.02	26.65	23.00	8.15	8.10	51.67	29.87	80.5	2.06	2.02	32.0	56.2

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	30.3	48.0	32.0	50.7	39.4	33.9	-44.8	.00
1.82	28.6	49.5	30.5	52.3	38.0	35.0	-43.6	.00
1.90	28.0	50.3	29.9	53.0	36.5	36.4	-42.0	.00
2.10	30.8	47.5	32.5	50.1	34.7	38.2	-38.6	.00
2.34	36.0	42.0	36.5	45.7	34.6	38.2	-33.0	.00
2.60	38.8	39.4	38.4	43.8	38.1	35.0	-4.0	.00
2.80	31.1	47.3	31.9	50.9	41.7	31.6	27.6	.00
2.88	28.4	50.1	30.1	53.0	39.0	34.0	27.4	.00
2.92	27.3	51.2	29.3	53.8	36.5	36.5	27.0	.00
1.78	40.3	61.5	40.1	60.5	59.1	54.0	-44.6	.00
1.82	39.3	62.4	39.3	61.3	57.9	55.3	-44.8	.00
1.90	39.1	62.6	38.9	61.8	56.3	56.8	-42.0	.00
2.10	41.5	60.0	41.3	59.3	54.4	58.6	-40.6	.00
2.34	46.3	54.4	45.2	55.4	54.5	58.7	-35.0	.00
2.60	49.8	50.5	47.5	53.2	57.5	55.7	-9.6	.00
2.80	42.9	58.4	41.0	59.6	60.0	53.1	28.6	.00
2.88	40.3	61.4	39.2	61.5	57.2	55.9	27.4	.00
2.92	39.5	62.3	38.7	61.9	55.1	57.9	26.0	.00

RUN 3 CLEARANCE - .057 PRESSURE RATIO - 1.70

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
15420.	.00	75.76	23.55	23.00	10.30	10.25	51.64	29.86	81.0	2.12	2.08	32.0	42.3

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	37.8	40.6	38.5	43.7	37.4	35.7	11.2	.00
1.82	37.7	40.7	38.3	43.9	37.1	35.9	10.0	.00
1.90	37.7	40.7	38.1	44.1	37.1	35.9	10.0	.00
2.10	37.0	41.4	37.3	45.1	37.2	35.9	16.0	.00
2.34	37.0	41.4	37.1	45.3	36.6	36.5	32.2	.00
2.60	37.3	41.1	37.1	45.3	37.0	36.0	40.4	.00
2.80	28.2	50.2	29.2	54.0	44.1	29.3	37.8	.00
2.88	19.7	58.7	23.0	61.0	42.9	30.5	38.0	.00
2.92	13.5	64.6	19.0	65.2	37.4	35.6	37.8	.00
1.78	48.4	52.0	47.8	52.9	57.6	55.5	19.6	.00
1.82	48.4	52.6	47.6	53.1	57.8	55.4	16.0	.00
1.90	48.1	52.3	47.2	53.4	57.8	55.4	12.8	.00
2.10	47.5	53.0	46.2	54.4	56.5	56.5	21.0	.00
2.34	48.0	52.7	46.2	54.5	56.1	57.0	38.2	.00
2.60	48.0	52.7	46.0	54.7	56.5	56.6	45.0	.00
2.80	42.5	58.0	40.0	60.6	59.6	53.5	33.2	.00
2.88	35.6	66.9	34.4	66.3	58.6	54.4	33.8	.00
2.92	31.1	72.0	30.9	69.6	54.6	58.3	35.0	.00

RUN 3 CLEARANCE - .057 PRESSURE RATIO - 1.70

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
16890.	.00	72.78	20.58	23.00	12.50	12.40	51.99	29.85	80.2	2.10	2.06	32.0	31.1

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	36.7	41.8	37.9	44.5	37.7	35.4	54.4	.00
1.82	35.7	42.8	37.0	45.4	37.6	35.6	52.0	.00
1.90	34.2	44.3	35.5	47.1	37.1	36.0	50.4	.00
2.10	31.7	46.7	33.1	49.8	36.5	36.5	50.2	.00
2.34	30.8	47.7	32.2	50.6	36.0	37.0	50.0	.00
2.60	30.5	48.1	31.6	51.5	36.7	36.3	54.8	.00
2.80	19.9	58.7	23.1	60.8	41.9	31.3	52.0	.00
2.88	11.6	66.6	17.5	66.9	40.4	32.7	47.8	.00
2.92	6.1	71.7	13.9	70.7	35.9	36.9	45.4	.00
1.78	49.5	50.8	49.1	51.6	57.4	55.8	64.2	.00
1.82	48.8	51.6	48.5	52.2	57.4	55.8	56.2	.00
1.90	47.4	53.2	47.0	53.7	57.0	56.1	50.2	.00
2.10	44.3	56.7	43.9	56.9	55.5	57.5	48.2	.00
2.34	42.4	59.0	41.8	58.9	54.8	58.3	48.2	.00
2.60	41.3	60.2	40.2	60.5	55.2	57.8	51.6	.00
2.80	34.0	68.8	33.3	67.3	57.2	55.7	50.0	.00
2.88	28.6	75.0	29.2	71.2	54.8	58.1	47.0	.00
2.92	25.9	78.0	27.7	72.6	51.8	60.9	45.2	.00

TABLE D2 (CONTINUED)

RUN 5 CLEARANCE - .052 PRESSURE RATIO - 1.30

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
10144.	.00	33.90	11.39	23.00	17.05	17.02	22.47	30.07	77.0	1.68	1.55	32.0	21.2

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	48.5	49.6	38.1	39.5	59.5	58.6	-11.4	1.07
1.82	48.3	49.8	37.9	39.7	59.4	58.7	-8.0	1.05
1.90	48.1	50.0	37.7	40.0	59.3	58.9	-8.0	1.02
2.10	47.9	50.1	37.3	40.4	59.2	59.0	5.2	1.01
2.34	48.0	50.0	37.1	40.6	59.2	59.1	22.0	1.03
2.60	48.0	50.0	36.8	41.0	59.4	58.7	44.2	1.05
2.80	44.5	53.3	34.5	43.9	60.8	57.2	47.4	1.09
2.88	42.0	55.7	32.7	46.1	60.4	57.7	46.2	1.14
2.92	39.9	57.6	31.4	47.7	59.1	59.1	47.2	1.19
1.78	46.4	47.6	46.5	48.0	54.3	53.0	-6.4	1.09
1.82	46.3	47.7	46.2	48.2	54.2	53.2	-5.8	1.07
1.90	46.1	47.9	46.0	48.4	53.9	53.4	-6.0	1.04
2.10	46.0	48.1	45.7	48.7	53.6	53.8	-.2	1.05
2.34	46.1	47.9	45.7	48.7	53.4	53.9	16.0	1.07
2.60	46.2	47.8	45.4	49.1	53.7	53.7	38.2	1.08
2.80	43.8	50.7	42.9	51.6	54.9	52.5	42.8	1.12
2.88	41.1	53.7	40.5	54.0	54.2	53.2	44.0	1.16
2.92	39.6	55.4	39.5	55.0	52.8	54.5	43.8	1.21

RUN 5 CLEARANCE - .052 PRESSURE RATIO - 1.55

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
14824.	.00	59.94	18.31	23.00	13.15	13.09	41.25	30.05	78.5	1.84	1.70	32.0	34.7

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	47.8	50.2	36.9	40.8	59.1	59.2	28.2	.66
1.82	47.7	50.3	36.7	40.9	59.1	59.2	28.0	.65
1.90	47.6	50.5	36.5	41.1	59.5	58.9	28.0	.63
2.10	46.6	51.5	35.4	42.5	59.2	59.1	33.0	.62
2.34	46.0	52.0	34.9	43.1	59.5	58.8	40.8	.63
2.60	46.1	51.8	34.8	43.2	59.6	58.8	50.4	.65
2.80	39.0	58.5	29.7	49.4	64.1	53.5	41.2	.68
2.88	32.2	64.6	25.0	55.2	63.0	54.8	40.0	.75
2.92	25.9	70.0	21.1	59.8	58.0	59.2	40.4	.85
1.78	45.5	48.7	45.0	49.5	54.0	53.4	41.0	.68
1.82	45.4	48.8	44.7	49.7	53.8	53.6	37.0	.67
1.90	45.4	48.8	44.6	49.8	53.7	53.8	32.1	.62
2.10	45.4	48.8	44.4	50.1	53.8	53.6	30.8	.62
2.34	45.5	48.7	44.4	50.1	53.9	53.6	40.0	.65
2.60	44.2	50.2	42.7	51.8	53.4	54.0	48.4	.66
2.80	39.5	55.7	37.5	57.1	56.0	51.4	39.4	.70
2.88	33.5	62.5	31.0	63.4	55.2	52.1	40.0	.74
2.92	29.2	67.4	29.1	65.2	51.5	55.7	37.4	.84

RUN 5 CLEARANCE - .052 PRESSURE RATIO - 1.70

RPM	TARE	PUVC	DPVC	H16	H19	H20	P5P	PATM	TRM	V4	V5	TCJ	TQ
16050.	.00	75.73	23.18	23.00	10.31	10.24	52.15	30.04	79.2	2.09	1.92	32.0	46.2

PROBE SURVEY DATA

R2	H1A	HATM	H1B	H2	H4	H5	ALF2	VT2
1.78	47.4	50.6	35.4	41.8	60.3	58.0	13.0	.63
1.82	47.4	50.7	35.5	41.6	60.1	58.2	9.5	.62
1.90	47.4	50.7	35.2	42.0	60.1	58.2	12.8	.61
2.10	46.8	51.2	34.6	42.8	60.3	58.0	22.0	.61
2.34	46.8	51.4	34.4	43.1	60.3	58.0	32.2	.63
2.60	47.0	51.0	34.4	43.2	60.8	57.5	42.0	.64
2.80	37.0	60.2	27.1	52.1	65.6	51.5	34.0	.67
2.88	27.4	68.8	20.5	60.2	65.0	52.5	35.6	.75
2.92	20.8	74.6	16.1	65.5	60.1	58.1	37.2	.88
1.78	45.3	49.0	44.1	50.4	54.6	53.0	21.6	.63
1.82	45.3	49.0	44.0	50.5	54.5	53.1	17.6	.62
1.90	45.4	49.3	44.0	50.5	54.5	53.0	17.6	.60
2.10	44.5	49.9	43.0	52.5	54.5	53.0	18.8	.62
2.34	44.9	49.4	42.5	52.0	54.0	53.5	36.8	.64
2.60	44.8	49.5	42.7	51.9	53.9	53.5	39.2	.66
2.80	38.1	57.2	34.5	60.0	57.6	49.8	33.2	.68
2.88	30.9	65.5	27.7	66.6	56.4	51.0	33.4	.74
2.92	25.5	71.6	23.7	70.4	51.8	55.4	33.4	.86

SCROLL AND GUIDE VANE TESTS OF ICP RADIAL TURBINE

TABLE D3 INPUT DATA

PT.	DPVC	PUVC	P5P	PATM	HATM	H1	SR	TRM	V4	V5
1	10.56	25.56	14.83	30.02	56.50	49.11	8.68	72.00	1.99	1.92
2	11.55	28.15	16.47	30.02	56.50	48.31	9.46	73.00	1.86	1.83
3	12.77	31.54	18.51	30.02	56.50	47.26	10.39	73.00	1.82	1.78
4	13.72	34.01	20.05	30.02	56.50	46.42	11.17	73.00	1.82	1.78
5	15.03	37.41	22.12	30.02	66.00	54.21	12.14	74.50	1.90	1.87
6	17.21	43.35	25.93	30.02	60.20	47.26	13.95	74.00	1.87	1.83
7	19.15	48.99	29.40	30.02	66.10	50.39	15.50	74.00	1.90	1.86
8	23.16	60.57	36.89	30.02	66.10	47.25	19.03	74.00	1.95	1.91

TCJ - 32.00 TARE - .00 STARE - 1.45

AIR TESTS OF ICP RADIAL TURBINE

TABLE E1 OVERALL PERFORMANCE VALUES WITHOUT BEARING LOSSES

REDUCED TO STANDARD AIR IN ACCORDANCE WITH NASA METHOD
TOTAL INLET PRESSURE =14.7 PSIA,TOTAL INLET TEMPERATURE =518.7 DEG.R
GAMMA =1.4,SPECIFIC HEAT CP AT CONSTANT PRESSURE =0.24 BTU/(LBM,DF)

						FLANGE ORIFICE TAPS		VENA CONTRACTA ORIFICE TAPS			
RUN	PT	SPEED	PRESS. RATIO	HEAD COEFF.	U/CO	FLOW RATE	EFFI- CIENCY	FLOW RATE	EFFI- CIENCY	POWER	TORQUE
		RPM				LBM/S	PCT.	LBM/S	PCT.	HP	FT-LB
1	1	7114.	1.290	5.143	.441	1.111	65.50	1.113	65.37	9.00	6.65
1	2	9669.	1.293	2.806	.597	1.042	74.79	1.042	74.85	9.72	5.28
1	3	11423.	1.292	2.005	.706	.969	73.81	.981	72.88	8.89	4.09
1	1	11377.	1.536	3.304	.550	1.319	78.10	1.315	78.34	20.93	9.66
1	2	14010.	1.538	2.183	.677	1.239	80.08	1.235	80.35	20.20	7.57
1	3	16924.	1.533	1.485	.820	1.130	74.32	1.127	74.51	16.98	5.27
1	1	11359.	1.676	3.938	.504	1.432	75.89	1.430	75.99	26.25	12.13
1	2	15015.	1.678	2.259	.665	1.336	82.37	1.334	82.52	26.64	9.32
1	3	17828.	1.682	1.610	.788	1.243	79.61	1.240	79.82	24.06	7.09
2	1	7173.	1.291	5.072	.444	1.142	65.89	1.141	65.94	9.33	6.83
2	2	9696.	1.293	2.790	.599	1.073	75.43	1.072	75.45	10.08	5.46
2	3	11381.	1.295	2.035	.701	1.003	73.37	1.004	73.30	9.22	4.26
2	1	11394.	1.535	3.290	.551	1.340	77.24	1.337	77.40	21.01	9.69
2	2	13954.	1.536	2.195	.675	1.264	80.36	1.263	80.42	20.64	7.77
2	3	16986.	1.541	1.491	.819	1.148	71.89	1.146	72.01	16.88	5.22
2	1	11340.	1.685	3.989	.501	1.450	74.09	1.450	74.11	26.20	12.14
2	2	14809.	1.683	2.334	.655	1.361	81.78	1.360	81.87	27.09	9.61
2	3	16580.	1.687	1.871	.731	1.302	81.13	1.303	81.07	25.83	8.18
3	1	7132.	1.291	5.121	.442	1.130	56.07	1.131	56.04	7.85	5.78
3	2	9550.	1.292	2.862	.591	1.064	60.72	1.063	60.82	8.02	4.41
3	3	11530.	1.292	1.965	.713	.984	52.82	.986	52.73	6.46	2.94
3	1	11343.	1.529	3.291	.551	1.330	70.34	1.331	70.31	18.83	8.72
3	2	13901.	1.536	2.212	.672	1.254	70.05	1.251	70.22	17.85	6.75
3	3	17328.	1.537	1.425	.838	1.121	58.15	1.123	58.02	13.26	4.02
3	1	11393.	1.681	3.936	.504	1.457	68.23	1.455	68.30	24.14	11.13
3	2	14527.	1.681	2.420	.643	1.364	70.12	1.362	70.22	23.22	8.40
3	3	17809.	1.685	1.618	.786	1.265	66.98	1.265	66.96	20.67	6.10
4	1	7250.	1.294	5.005	.447	1.129	65.98	1.129	65.99	9.32	6.75
4	2	9753.	1.294	2.766	.601	1.059	74.48	1.059	74.48	9.86	5.31
4	3	11604.	1.295	1.956	.715	.988	71.93	.987	71.98	8.90	4.03
4	1	11534.	1.538	3.224	.557	1.323	77.21	1.322	77.22	20.82	9.48
4	2	14169.	1.540	2.142	.683	1.246	78.46	1.240	78.85	19.98	7.41
4	3	17026.	1.539	1.481	.822	1.130	71.80	1.129	71.83	16.56	5.11
4	1	11422.	1.682	3.917	.505	1.439	74.84	1.439	74.84	26.16	12.03
4	2	15212.	1.683	2.213	.672	1.339	80.98	1.338	81.06	26.40	9.11
4	3	17868.	1.681	1.599	.791	1.253	77.53	1.251	77.69	23.59	6.93
5	1	7121.	1.294	5.185	.439	1.120	66.74	1.118	66.88	9.34	6.89
5	2	9620.	1.291	2.817	.596	1.050	74.70	1.043	75.16	9.71	5.30
5	3	11493.	1.295	1.997	.708	.983	72.04	.982	72.11	8.88	4.06
5	1	11370.	1.536	3.306	.550	1.315	76.84	1.311	77.05	20.53	9.48
5	2	13862.	1.534	2.217	.672	1.246	79.97	1.243	80.15	20.18	7.65
5	3	14501.	1.535	2.031	.702	1.220	78.93	1.216	79.18	19.55	7.08
5	4	17435.	1.537	1.409	.843	1.106	69.93	1.102	70.21	15.75	4.74
5	1	11350.	1.682	3.967	.502	1.441	74.34	1.438	74.53	26.03	12.04
5	2	14570.	1.679	2.401	.645	1.364	80.71	1.358	81.05	26.67	9.61
5	3	18170.	1.680	1.545	.805	1.232	75.67	1.226	76.02	22.59	6.53

TABLE E 2 OVERALL PERFORMANCE VALUES WITH MINIMUM BEARING LOSSES

REDUCED TO STANDARD AIR IN ACCORDANCE WITH NASA METHOD
TOTAL INLET PRESSURE =14.7 PSIA,TOTAL INLET TEMPERATURE =518.7 DEG.R
GAMMA =1.4,SPECIFIC HEAT CP AT CONSTANT PRESSURE =0.24 BTU/(LBM,DF)

						FLANGE ORIFICE TAPS		VENA CONTRACTA ORIFICE TAPS			
RUN	PT	SPEED	PRESS. RATIO	HEAD COEFF.	U/CO	FLOW RATE	EFFI-CIENCY	FLOW RATE	EFFI-CIENCY	POWER	TORQUE
		RPM				LBM/S	PCT.	LBM/S	PCT.	HP	FT-LB
1	1	7114.	1.290	5.143	.441	1.111	68.16	1.113	68.03	9.37	6.92
1	2	9669.	1.293	2.806	.597	1.042	80.24	1.042	80.31	10.43	5.67
1	3	11423.	1.292	2.005	.706	.969	81.54	.981	80.51	9.82	4.52
1	1	11377.	1.536	3.304	.550	1.319	81.01	1.315	81.27	21.71	10.02
1	2	14010.	1.538	2.183	.677	1.239	84.01	1.235	84.29	21.20	7.95
1	3	16924.	1.533	1.485	.820	1.130	79.28	1.127	79.48	18.11	5.62
1	1	11359.	1.676	3.938	.504	1.432	77.97	1.430	78.07	26.96	12.47
1	2	15015.	1.678	2.259	.665	1.336	85.35	1.334	85.50	27.60	9.66
1	3	17828.	1.682	1.610	.788	1.243	83.08	1.240	83.29	25.11	7.40
2	1	7173.	1.291	5.072	.444	1.142	68.51	1.141	68.57	9.70	7.11
2	2	9696.	1.293	2.790	.599	1.073	80.76	1.072	80.78	10.80	5.85
2	3	11381.	1.295	2.035	.701	1.003	80.73	1.004	80.65	10.15	4.68
2	1	11394.	1.535	3.290	.551	1.340	80.12	1.337	80.29	21.80	10.05
2	2	13954.	1.536	2.195	.675	1.264	84.21	1.263	84.28	21.63	8.14
2	3	16986.	1.541	1.491	.819	1.148	76.69	1.146	76.82	18.01	5.57
2	1	11340.	1.685	3.989	.501	1.450	76.11	1.450	76.13	26.92	12.47
2	2	14809.	1.683	2.334	.655	1.361	84.64	1.360	84.73	28.04	9.94
2	3	16580.	1.687	1.871	.731	1.302	84.31	1.303	84.26	26.84	8.50
3	1	7132.	1.291	5.121	.442	1.130	58.71	1.131	58.68	8.22	6.05
3	2	9550.	1.292	2.862	.591	1.064	66.01	1.063	66.11	8.72	4.79
3	3	11530.	1.292	1.965	.713	.984	60.59	.986	60.48	7.40	3.37
3	1	11343.	1.529	3.291	.551	1.330	73.28	1.331	73.24	19.62	9.08
3	2	13901.	1.536	2.212	.672	1.254	73.93	1.251	74.11	18.84	7.12
3	3	17328.	1.537	1.425	.838	1.121	63.16	1.123	63.01	14.40	4.36
3	1	11393.	1.681	3.936	.504	1.457	70.26	1.455	70.34	24.86	11.46
3	2	14527.	1.681	2.420	.643	1.364	72.96	1.362	73.07	24.17	8.74
3	3	17809.	1.685	1.618	.786	1.265	70.39	1.265	70.38	21.73	6.41
4	1	7250.	1.294	5.005	.447	1.129	68.64	1.129	68.65	9.69	7.02
4	2	9753.	1.294	2.766	.601	1.059	79.86	1.059	79.86	10.57	5.69
4	3	11604.	1.295	1.956	.715	.988	79.57	.987	79.63	9.84	4.46
4	1	11534.	1.538	3.224	.557	1.323	80.14	1.322	80.15	21.61	9.84
4	2	14169.	1.540	2.142	.683	1.246	82.39	1.240	82.80	20.98	7.78
4	3	17026.	1.539	1.481	.822	1.130	76.73	1.129	76.76	17.69	5.46
4	1	11422.	1.682	3.917	.505	1.439	76.89	1.439	76.88	26.88	12.36
4	2	15212.	1.683	2.213	.672	1.339	83.96	1.338	84.03	27.37	9.45
4	3	17868.	1.681	1.599	.791	1.253	81.00	1.251	81.16	24.64	7.24
5	1	7121.	1.294	5.185	.439	1.120	69.36	1.118	69.50	9.71	7.16
5	2	9620.	1.291	2.817	.596	1.050	80.12	1.043	80.62	10.42	5.69
5	3	11493.	1.295	1.997	.708	.983	79.65	.982	79.73	9.82	4.49
5	1	11370.	1.536	3.306	.550	1.315	79.77	1.311	79.99	21.31	9.84
5	2	13862.	1.534	2.217	.672	1.246	83.87	1.243	84.06	21.16	8.02
5	3	14501.	1.535	2.031	.702	1.220	83.06	1.216	83.32	20.57	7.45
5	4	17435.	1.537	1.409	.843	1.106	74.99	1.102	75.29	16.88	5.09
5	1	11350.	1.682	3.967	.502	1.441	76.38	1.438	76.57	26.74	12.37
5	2	14570.	1.679	2.401	.645	1.364	83.55	1.358	83.90	27.60	9.95
5	3	18170.	1.680	1.545	.805	1.232	79.14	1.226	79.51	23.63	6.83

AIR TESTS OF ICP RADIAL TURBINE

TABLE E 3 OVERALL PERFORMANCE VALUES WITH MAXIMUM BEARING LOSSES

REDUCED TO STANDARD AIR IN ACCORDANCE WITH NASA METHOD
TOTAL INLET PRESSURE =14.7 PSIA,TOTAL INLET TEMPERATURE =518.7 DEG.R
GAMMA =1.4,SPECIFIC HEAT CP AT CONSTANT PRESSURE =0.24 BTU/(LBM,DF)

						FLANGE ORIFICE TAPS		VENA CONTRACTA ORIFICE TAPS			
RUN	PT	SPEED	PRESS. RATIO	HEAD COEFF.	U/CO	FLOW RATE	EFFI-CIENCY	FLOW RATE	EFFI-CIENCY	POWER	TORQUE
		RPM				LBM/S	PCT.	LBM/S	PCT.	HP	FT-LB
1	1	7114.	1.290	5.143	.441	1.111	69.22	1.113	69.09	9.52	7.03
1	2	9669.	1.293	2.806	.597	1.042	81.37	1.042	81.43	10.58	5.75
1	3	11423.	1.292	2.005	.706	.969	82.81	.981	81.76	9.98	4.59
1	1	11377.	1.536	3.304	.550	1.319	81.49	1.315	81.74	21.84	10.08
1	2	14010.	1.538	2.183	.677	1.239	84.67	1.235	84.95	21.36	8.01
1	3	16924.	1.533	1.485	.820	1.130	80.37	1.127	80.57	18.36	5.70
1	1	11359.	1.676	3.938	.504	1.432	78.30	1.430	78.40	27.08	12.52
1	2	15015.	1.678	2.259	.665	1.336	85.89	1.334	86.04	27.78	9.72
1	3	17828.	1.682	1.610	.788	1.243	83.94	1.240	84.16	25.37	7.47
2	1	7173.	1.291	5.072	.444	1.142	69.55	1.141	69.60	9.85	7.21
2	2	9696.	1.293	2.790	.599	1.073	81.85	1.072	81.87	10.94	5.93
2	3	11381.	1.295	2.035	.701	1.003	81.94	1.004	81.86	10.30	4.75
2	1	11394.	1.535	3.290	.551	1.340	80.59	1.337	80.76	21.92	10.11
2	2	13954.	1.536	2.195	.675	1.264	84.85	1.263	84.92	21.79	8.20
2	3	16986.	1.541	1.491	.819	1.148	77.76	1.146	77.89	18.26	5.65
2	1	11340.	1.685	3.989	.501	1.450	76.44	1.450	76.45	27.03	12.52
2	2	14809.	1.683	2.334	.655	1.361	85.16	1.360	85.25	28.21	10.00
2	3	16580.	1.687	1.871	.731	1.302	85.00	1.303	84.94	27.06	8.57
3	1	7132.	1.291	5.121	.442	1.130	59.76	1.131	59.72	8.36	6.16
3	2	9550.	1.292	2.862	.591	1.064	67.12	1.063	67.22	8.86	4.87
3	3	11530.	1.292	1.965	.713	.984	61.85	.986	61.74	7.56	3.44
3	1	11343.	1.529	3.291	.551	1.330	73.76	1.331	73.72	19.75	9.14
3	2	13901.	1.536	2.212	.672	1.254	74.58	1.251	74.76	19.01	7.18
3	3	17328.	1.537	1.425	.838	1.121	64.33	1.123	64.18	14.66	4.44
3	1	11393.	1.681	3.936	.504	1.457	70.60	1.455	70.67	24.97	11.51
3	2	14527.	1.681	2.420	.643	1.364	73.45	1.362	73.56	24.33	8.80
3	3	17809.	1.685	1.618	.786	1.265	71.23	1.265	71.22	21.98	6.48
4	1	7250.	1.294	5.005	.447	1.129	69.68	1.129	69.69	9.84	7.13
4	2	9753.	1.294	2.766	.601	1.059	80.97	1.059	80.97	10.72	5.77
4	3	11604.	1.295	1.956	.715	.988	80.81	.987	80.87	10.00	4.52
4	1	11534.	1.538	3.224	.557	1.323	80.62	1.322	80.63	21.74	9.90
4	2	14169.	1.540	2.142	.683	1.246	83.04	1.240	83.45	21.15	7.84
4	3	17026.	1.539	1.481	.822	1.130	77.80	1.129	77.83	17.94	5.53
4	1	11422.	1.682	3.917	.505	1.439	77.22	1.439	77.22	26.99	12.41
4	2	15212.	1.683	2.213	.672	1.339	84.50	1.338	84.58	27.55	9.51
4	3	17868.	1.681	1.599	.791	1.253	81.85	1.251	82.01	24.90	7.32
5	1	7121.	1.294	5.185	.439	1.120	70.39	1.118	70.54	9.86	7.27
5	2	9620.	1.291	2.817	.596	1.050	81.24	1.043	81.74	10.57	5.77
5	3	11493.	1.295	1.997	.708	.983	80.89	.982	80.97	9.97	4.56
5	1	11370.	1.536	3.306	.550	1.315	80.25	1.311	80.47	21.44	9.90
5	2	13862.	1.534	2.217	.672	1.246	84.51	1.243	84.71	21.33	8.08
5	3	14501.	1.535	2.031	.702	1.220	83.77	1.216	84.04	20.75	7.52
5	4	17435.	1.537	1.409	.843	1.106	76.18	1.102	76.49	17.15	5.17
5	1	11350.	1.682	3.967	.502	1.441	76.71	1.438	76.90	26.86	12.43
5	2	14570.	1.679	2.401	.645	1.364	84.05	1.358	84.40	27.77	10.01
5	3	18170.	1.680	1.545	.805	1.232	80.05	1.226	80.42	23.90	6.91

AIR TESTS OF ICP RADIAL TURBINE

TABLE E4 BLADING PARAMETERS WITHOUT BEARING LOSSES

REDUCED TO STANDARD AIR IN ACCORDANCE WITH NASA METHOD
TOTAL INLET PRESSURE =14.7 PSIA, TOTAL INLET TEMPERATURE =518.7 DEG.R
GAMMA =1.4, SPECIFIC HEAT CP AT CONSTANT PRESSURE =0.24 BTU/(LBM.DF)

RUN	PT	SPEED RPM	PRESS. RATIO	U/CO	DEGREE OF REACTION	ANGLE BETA1 DEG.	AVERAGE RADIUS RATIO R2/R1	DISCHARGE ANGLE ALPHA 2 FLANGE DEG.	DISCHARGE ANGLE ALPHA 2 VENA.C DEG.	VELOCITY RATIO VM2/U1 FLANGE	VELOCITY RATIO VM2/U1 VENA.C
1	1	7114.	1.290	.441	.260	67.0	.517	14.09	15.88	.184	.182
1	2	9669.	1.293	.597	.356	40.4	.521	66.26	65.91	.108	.109
1	3	11423.	1.292	.706	.447	-25.6	.527	78.52	80.12	.070	.063
1	1	11377.	1.536	.550	.331	52.7	.519	6.37	3.96	.194	.198
1	2	14010.	1.538	.677	.432	-8.3	.523	56.24	54.98	.129	.131
1	3	16924.	1.533	.820	.555	-66.5	.539	72.49	72.18	.094	.095
1	1	11359.	1.676	.504	.306	60.3	.517	-20.68	-21.30	.238	.239
1	2	15015.	1.678	.665	.420	.8	.523	42.64	41.69	.150	.151
1	3	17828.	1.682	.788	.529	-60.5	.532	62.93	62.38	.117	.118

1 3 NO FLOW TO RADIUS R2 = 1.780 IN. OF DISCHARGE ANNULUS

2	1	7173.	1.291	.444	.257	66.8	.517	17.38	16.63	.180	.181
2	2	9696.	1.293	.599	.348	41.0	.522	66.54	66.46	.107	.107
2	3	11381.	1.295	.701	.438	-21.2	.527	79.77	79.88	.065	.064
2	1	11394.	1.535	.551	.320	53.3	.520	23.23	21.70	.174	.176
2	2	13954.	1.536	.675	.415	-2.6	.525	59.70	59.34	.123	.123
2	3	16986.	1.541	.819	.556	-66.4	.537	76.18	75.99	.081	.082
2	1	11340.	1.685	.501	.305	60.7	.517	-10.27	-10.43	.218	.218
2	2	14809.	1.683	.655	.412	8.2	.522	42.25	41.83	.151	.151
2	3	16580.	1.687	.731	.483	-42.5	.526	56.35	56.63	.129	.129

3	1	7132.	1.291	.442	.258	66.9	.517	-89.67	-89.60	-.003	-.004
3	2	9550.	1.292	.591	.338	44.0	.522	-85.76	-85.83	-.048	-.047
3	3	11530.	1.292	.713	.455	-30.5	.527	-83.72	-83.68	-.081	-.082
3	1	11343.	1.529	.551	.319	53.4	.520	73.49	73.63	.088	.087
3	2	13901.	1.536	.672	.424	-4.0	.524	83.64	83.38	.045	.047
3	3	17328.	1.537	.838	.566	-68.7	.546	88.07	88.15	.017	.016
3	1	11393.	1.681	.504	.308	60.2	.517	57.77	57.17	.125	.126
3	2	14527.	1.681	.643	.419	11.8	.521	80.49	80.30	.061	.062
3	3	17809.	1.685	.786	.531	-60.5	.530	83.93	83.96	.044	.044

3 3 NO FLOW TO RADIUS R2 = 1.880 IN. OF DISCHARGE ANNULUS

4	1	7250.	1.294	.447	.259	66.6	.517	20.97	20.97	.176	.176
4	2	9753.	1.294	.601	.347	40.4	.522	71.42	71.49	.094	.094
4	3	11604.	1.295	.715	.449	-29.7	.528	82.03	81.97	.054	.055
4	1	11534.	1.538	.557	.328	51.8	.519	26.52	26.33	.170	.170
4	2	14169.	1.540	.683	.429	-10.6	.525	65.78	64.49	.110	.113
4	3	17026.	1.539	.822	.548	-66.0	.544	76.90	76.87	.079	.079
4	1	11422.	1.682	.505	.306	60.1	.518	-11.09	-11.09	.219	.219
4	2	15212.	1.683	.672	.425	-4.2	.523	51.99	51.64	.136	.137
4	3	17868.	1.681	.791	.528	-60.7	.533	68.53	68.19	.104	.105

4 3 NO FLOW TO RADIUS R2 = 1.860 IN. OF DISCHARGE ANNULUS

5	1	7121.	1.294	.439	.254	67.2	.517	-4.59	-6.41	.209	.212
5	2	9620.	1.291	.596	.350	41.4	.521	67.55	65.63	.105	.109
5	3	11493.	1.295	.708	.444	-25.5	.527	81.82	81.72	.055	.056
5	1	11370.	1.536	.550	.327	53.0	.519	21.44	19.26	.176	.179
5	2	13862.	1.534	.672	.423	-3.1	.524	57.50	56.59	.127	.128
5	3	14501.	1.535	.702	.453	-25.3	.525	63.80	62.92	.114	.116
5	4	17435.	1.537	.843	.572	-69.5	.546	77.11	76.73	.078	.080
5	1	11350.	1.682	.502	.304	60.6	.517	-9.85	-11.50	.217	.220
5	2	14570.	1.679	.645	.401	15.2	.522	47.49	45.51	.143	.146
5	3	18170.	1.680	.805	.538	-63.4	.536	71.74	71.08	.095	.097

5 4 NO FLOW TO RADIUS R2 = 1.880 IN. OF DISCHARGE ANNULUS

AIR TESTS OF ICP RADIAL TURBINE

TABLE E5 BLADING PARAMETERS WITH MINIMUM BEARING LOSSES

REDUCED TO STANDARD AIR IN ACCORDANCE WITH NASA METHOD
TOTAL INLET PRESSURE =14.7 PSIA,TOTAL INLET TEMPERATURE =518.7 DEG.R
GAMMA =1.4,SPECIFIC HEAT CP AT CONSTANT PRESSURE =0.24 BTU/(LBM,DF)

RUN	PT	SPEED RPM	PRESS. RATIO	U/CO	DEGREE OF REACTION	ANGLE BETA1 DEG.	AVERAGE RADIUS RATIO R2/R1	DISCHARGE ANGLE ALPHA 2 FLANGE DEG.	DISCHARGE ANGLE ALPHA 2 VENA.C DEG.	VELOCITY RATIO VM2/U1 FLANGE	VELOCITY RATIO VM2/U1 VENA.C
1	1	7114.	1.290	.441	.260	67.0	.517	-20.12	-18.95	.236	.234
1	2	9669.	1.293	.597	.356	40.4	.521	30.70	30.19	.165	.166
1	3	11423.	1.292	.706	.447	-25.6	.527	57.34	61.31	.128	.120
1	1	11377.	1.536	.550	.331	52.7	.519	-17.09	-18.66	.231	.234
1	2	14010.	1.538	.677	.432	-8.3	.523	34.49	32.73	.161	.163
1	3	16924.	1.533	.820	.555	-66.5	.539	62.28	61.77	.120	.121
1	1	11359.	1.676	.504	.306	60.3	.517	-32.12	-32.52	.269	.270
1	2	15015.	1.678	.665	.420	.8	.523	22.86	21.77	.175	.177
1	3	17828.	1.682	.788	.529	-60.5	.532	52.14	51.33	.138	.139
1	3	NO FLOW TO RADIUS R2 = 1.780 IN. OF DISCHARGE ANNULUS									
2	1	7173.	1.291	.444	.257	66.8	.517	-17.37	-17.98	.231	.232
2	2	9696.	1.293	.599	.348	41.0	.522	32.73	32.57	.163	.163
2	3	11381.	1.295	.701	.438	-21.2	.527	61.05	61.37	.120	.120
2	1	11394.	1.535	.551	.320	53.3	.520	-4.52	-5.90	.210	.212
2	2	13954.	1.536	.675	.415	-2.6	.525	40.00	39.61	.154	.155
2	3	16986.	1.541	.819	.556	-66.4	.537	67.81	67.54	.107	.107
2	1	11340.	1.685	.501	.305	60.7	.517	-25.29	-25.40	.248	.249
2	2	14809.	1.683	.655	.412	8.2	.522	22.64	21.99	.175	.176
2	3	16580.	1.687	.731	.483	-42.5	.526	42.36	42.60	.151	.151
3	1	7132.	1.291	.442	.258	66.9	.517	83.05	83.17	.048	.047
3	2	9550.	1.292	.591	.338	44.0	.522	89.00	88.86	.009	.010
3	3	11530.	1.292	.713	.455	-30.5	.527	-87.62	-87.55	-.024	-.025
3	1	11343.	1.529	.551	.319	53.4	.520	58.52	58.76	.124	.124
3	2	13901.	1.536	.672	.424	-4.0	.524	76.60	76.20	.077	.079
3	3	17328.	1.537	.838	.566	-68.7	.546	84.50	84.61	.042	.041
3	1	11393.	1.681	.504	.308	60.2	.517	37.91	37.06	.155	.156
3	2	14527.	1.681	.643	.419	11.8	.521	73.77	73.44	.087	.088
3	3	17809.	1.685	.786	.531	-60.5	.530	79.97	80.01	.064	.064
3	3	NO FLOW TO RADIUS R2 = 1.880 IN. OF DISCHARGE ANNULUS									
4	1	7250.	1.294	.447	.259	66.6	.517	-15.12	-15.12	.226	.226
4	2	9753.	1.294	.601	.347	40.4	.522	42.79	42.79	.150	.150
4	3	11604.	1.295	.715	.449	-29.7	.528	66.11	65.97	.109	.110
4	1	11534.	1.538	.557	.328	51.8	.519	-1.71	-1.88	.206	.206
4	2	14169.	1.540	.683	.429	-10.6	.525	49.32	47.10	.141	.144
4	3	17026.	1.539	.822	.548	-66.0	.544	68.94	68.89	.105	.105
4	1	11422.	1.682	.505	.306	60.1	.518	-25.71	-25.71	.250	.250
4	2	15212.	1.683	.672	.425	-4.2	.523	34.81	34.23	.161	.161
4	3	17868.	1.681	.791	.528	-60.7	.533	59.71	59.19	.124	.125
4	3	NO FLOW TO RADIUS R2 = 1.860 IN. OF DISCHARGE ANNULUS									
5	1	7121.	1.294	.439	.254	67.2	.517	-29.62	-30.61	.260	.263
5	2	9620.	1.291	.596	.350	41.4	.521	33.59	29.33	.162	.167
5	3	11493.	1.295	.708	.444	-25.5	.527	65.20	64.99	.111	.112
5	1	11370.	1.536	.550	.327	53.0	.519	-6.43	-8.26	.212	.215
5	2	13862.	1.534	.672	.423	-3.1	.524	36.22	34.93	.159	.161
5	3	14501.	1.535	.702	.453	-25.3	.525	46.32	44.87	.145	.147
5	4	17435.	1.537	.843	.572	-69.5	.546	69.49	68.96	.104	.105
5	1	11350.	1.682	.502	.304	60.6	.517	-24.98	-26.16	.248	.251
5	2	14570.	1.679	.645	.401	15.2	.522	28.43	25.71	.168	.172
5	3	18170.	1.680	.805	.538	-63.4	.536	64.38	63.44	.115	.117
5	4	NO FLOW TO RADIUS R2 = 1.880 IN. OF DISCHARGE ANNULUS									

TABLE E6 BLADING PARAMETERS WITH MAXIMUM BEARING LOSSES

REDUCED TO STANDARD AIR IN ACCORDANCE WITH NASA METHOD
TOTAL INLET PRESSURE =14.7 PSIA,TOTAL INLET TEMPERATURE =518.7 DEG.R
GAMMA =1.4,SPECIFIC HEAT CP AT CONSTANT PRESSURE =0.24 BTU/(LBM,DF)

RUN	PT	SPEED RPM	PRESS. RATIO	U/CO	DEGREE OF REACTION	ANGLE BETA1 DEG.	AVERAGE RADIUS RATIO R2/R1	DISCHARGE ANGLE ALPHA 2 FLANGE DEG.	DISCHARGE ANGLE ALPHA 2 VENA.C DEG.	VELOCITY RATIO VM2/U1 FLANGE	VELOCITY RATIO VM2/U1 VENA.C
1	1	7114.	1.290	.441	.260	67.0	.517	-28.50	-27.63	.257	.254
1	2	9669.	1.293	.597	.356	40.4	.521	20.97	20.45	.177	.178
1	3	11423.	1.292	.706	.447	-25.6	.527	52.03	56.44	.137	.129
1	1	11377.	1.536	.550	.331	52.7	.519	-20.04	-21.48	.237	.240
1	2	14010.	1.538	.677	.432	-8.3	.523	30.35	28.39	.166	.169
1	3	16924.	1.533	.820	.555	-66.5	.539	59.49	58.93	.126	.127
1	1	11359.	1.676	.504	.306	60.3	.517	-33.53	-33.91	.274	.275
1	2	15015.	1.678	.665	.420	.8	.523	19.11	18.01	.180	.181
1	3	17828.	1.682	.788	.529	-60.5	.532	48.99	48.12	.143	.144

1 3 NO FLOW TO RADIUS R2 = 1.780 IN. OF DISCHARGE ANNULUS

RUN	PT	SPEED RPM	PRESS. RATIO	U/CO	DEGREE OF REACTION	ANGLE BETA1 DEG.	AVERAGE RADIUS RATIO R2/R1	DISCHARGE ANGLE ALPHA 2 FLANGE DEG.	DISCHARGE ANGLE ALPHA 2 VENA.C DEG.	VELOCITY RATIO VM2/U1 FLANGE	VELOCITY RATIO VM2/U1 VENA.C
2	1	7173.	1.291	.444	.257	66.8	.517	-26.14	-26.59	.250	.252
2	2	9696.	1.293	.599	.348	41.0	.522	23.52	23.35	.174	.174
2	3	11381.	1.295	.701	.438	-21.2	.527	56.35	56.71	.129	.129
2	1	11394.	1.535	.551	.320	53.3	.520	-8.26	-9.55	.215	.217
2	2	13954.	1.536	.675	.415	-2.6	.525	36.03	35.62	.159	.160
2	3	16986.	1.541	.819	.556	-66.4	.537	65.52	65.23	.112	.113
2	1	11340.	1.685	.501	.305	60.7	.517	-27.09	-27.19	.253	.254
2	2	14809.	1.683	.655	.412	8.2	.522	18.94	18.29	.180	.181
2	3	16580.	1.687	.731	.483	-42.5	.526	38.85	39.11	.156	.156

RUN	PT	SPEED RPM	PRESS. RATIO	U/CO	DEGREE OF REACTION	ANGLE BETA1 DEG.	AVERAGE RADIUS RATIO R2/R1	DISCHARGE ANGLE ALPHA 2 FLANGE DEG.	DISCHARGE ANGLE ALPHA 2 VENA.C DEG.	VELOCITY RATIO VM2/U1 FLANGE	VELOCITY RATIO VM2/U1 VENA.C
3	1	7132.	1.291	.442	.258	66.9	.517	78.66	78.88	.069	.068
3	2	9550.	1.292	.591	.338	44.0	.522	87.49	87.33	.021	.022
3	3	11530.	1.292	.713	.455	-30.5	.527	-88.44	-88.36	-.015	-.016
3	1	11343.	1.529	.551	.319	53.4	.520	55.25	55.51	.130	.129
3	2	13901.	1.536	.672	.424	-4.0	.524	75.10	74.67	.083	.084
3	3	17328.	1.537	.838	.566	-68.7	.546	83.50	83.64	.048	.047
3	1	11393.	1.681	.504	.308	60.2	.517	34.01	33.13	.160	.161
3	2	14527.	1.681	.643	.419	11.8	.521	72.36	72.01	.091	.092
3	3	17809.	1.685	.786	.531	-60.5	.530	78.83	78.86	.069	.069

3 3 NO FLOW TO RADIUS R2 = 1.880 IN. OF DISCHARGE ANNULUS

RUN	PT	SPEED RPM	PRESS. RATIO	U/CO	DEGREE OF REACTION	ANGLE BETA1 DEG.	AVERAGE RADIUS RATIO R2/R1	DISCHARGE ANGLE ALPHA 2 FLANGE DEG.	DISCHARGE ANGLE ALPHA 2 VENA.C DEG.	VELOCITY RATIO VM2/U1 FLANGE	VELOCITY RATIO VM2/U1 VENA.C
4	1	7250.	1.294	.447	.259	66.6	.517	-24.29	-24.41	.246	.246
4	2	9753.	1.294	.601	.347	40.4	.522	34.11	34.11	.161	.161
4	3	11604.	1.295	.715	.449	-29.7	.528	62.18	61.95	.118	.119
4	1	11534.	1.538	.557	.328	51.8	.519	-5.80	-5.80	.212	.212
4	2	14169.	1.540	.683	.429	-10.6	.525	45.78	43.56	.146	.149
4	3	17026.	1.539	.822	.548	-66.0	.544	66.79	66.74	.110	.111
4	1	11422.	1.682	.505	.306	60.1	.518	-27.65	-27.55	.255	.255
4	2	15212.	1.683	.672	.425	-4.2	.523	31.26	30.66	.165	.166
4	3	17868.	1.681	.791	.528	-60.7	.533	57.12	56.56	.129	.130

4 3 NO FLOW TO RADIUS R2 = 1.860 IN. OF DISCHARGE ANNULUS

RUN	PT	SPEED RPM	PRESS. RATIO	U/CO	DEGREE OF REACTION	ANGLE BETA1 DEG.	AVERAGE RADIUS RATIO R2/R1	DISCHARGE ANGLE ALPHA 2 FLANGE DEG.	DISCHARGE ANGLE ALPHA 2 VENA.C DEG.	VELOCITY RATIO VM2/U1 FLANGE	VELOCITY RATIO VM2/U1 VENA.C
5	1	7121.	1.294	.439	.254	67.2	.517	-35.50	-36.17	.281	.284
5	2	9620.	1.291	.596	.350	41.4	.521	23.97	19.57	.174	.179
5	3	11493.	1.295	.708	.444	-25.5	.527	61.06	60.74	.120	.121
5	1	11370.	1.536	.550	.327	53.0	.519	-10.16	-11.86	.218	.221
5	2	13862.	1.534	.672	.423	-3.1	.524	32.02	30.69	.164	.166
5	3	14501.	1.535	.702	.453	-25.3	.525	42.51	41.10	.151	.153
5	4	17435.	1.537	.843	.572	-69.5	.546	67.27	66.70	.110	.111
5	1	11350.	1.682	.502	.304	60.6	.517	-26.89	-27.99	.253	.256
5	2	14570.	1.679	.645	.401	15.2	.522	24.75	22.17	.173	.176
5	3	18170.	1.680	.805	.538	-63.4	.536	62.08	61.08	.120	.122

5 4 NO FLOW TO RADIUS R2 = 1.880 IN. OF DISCHARGE ANNULUS

REDUCED TO STANDARD AIR IN ACCORDANCE WITH NASA METHOD
TOTAL INLET PRESSURE =14.7 PSIA,TOTAL INLET TEMPERATURE =518.7 DEG.R
GAMMA =1.4,SPECIFIC HEAT CP AT CONSTANT PRESSURE =0.24 BTU/(LBM,DF)

RUN	PT	SPEED RPM	PRESS. RATIO	U/CO	STATOR LOSS COEFFICIENT FOR AREA CALCULATION FLANGE	STATOR LOSS COEFFICIENT FOR AREA CALCULATION VENA.C	ROTOR LOSS COEFFICIENTS FOR AREAS FLANGE	ROTOR LOSS COEFFICIENTS FOR AREAS VENA.C	ROTOR LOSS COEFFICIENTS FOR EFFICIENCY FLANGE	ROTOR LOSS COEFFICIENTS FOR EFFICIENCY VENA.C
1	1	7114.	1.290	.441	.107	.104	.352	.350	.646	.654
1	2	9669.	1.293	.597	.133	.134	.325	.326	.730	.725
1	3	11423.	1.292	.706	.155	.135	.348	.331	.819	.853
1	1	11377.	1.536	.550	.037	.041	.245	.250	.352	.331
1	2	14010.	1.538	.677	.059	.065	.267	.272	.517	.500
1	3	16924.	1.533	.820	.070	.074	.253	.257	.538	.527
1	1	11359.	1.676	.504	-.009	-.007	.210	.211	.257	.248
1	2	15015.	1.678	.665	.031	.034	.185	.187	.368	.357
1	3	17828.	1.682	.788	.048	.053	.192	.196	.376	.363
2	1	7173.	1.291	.444	.066	.068	.291	.292	.642	.639
2	2	9696.	1.293	.599	.095	.095	.222	.222	.706	.705
2	3	11381.	1.295	.701	.113	.112	.285	.284	.843	.846
2	1	11394.	1.535	.551	.017	.020	.148	.151	.428	.416
2	2	13954.	1.536	.675	.039	.041	.138	.139	.506	.500
2	3	16986.	1.541	.819	.048	.051	.244	.246	.662	.657
2	1	11340.	1.685	.501	-.027	-.027	.203	.203	.393	.392
2	2	14809.	1.683	.655	.008	.010	.171	.173	.398	.393
2	3	16580.	1.687	.731	.021	.020	.211	.210	.422	.427
3	1	7132.	1.291	.442	.082	.081	.318	.317	1.000	1.000
3	2	9550.	1.292	.591	.114	.117	.209	.211	.941	.944
3	3	11530.	1.292	.713	.119	.116	.333	.330	.758	.753
3	1	11343.	1.529	.551	.027	.026	.148	.147	.853	.855
3	2	13901.	1.536	.672	.044	.048	.230	.234	.939	.935
3	3	17328.	1.537	.838	.071	.067	.241	.238	.984	.985
3	1	11393.	1.681	.504	-.037	-.035	.195	.196	.798	.794
3	2	14527.	1.681	.643	-.004	-.001	.268	.270	.916	.914
3	3	17809.	1.685	.786	.017	.017	.193	.193	.915	.915
4	1	7250.	1.294	.447	.088	.088	.311	.311	.655	.655
4	2	9753.	1.294	.601	.118	.118	.224	.224	.765	.766
4	3	11604.	1.295	.715	.126	.127	.288	.289	.882	.881
4	1	11534.	1.538	.557	.036	.036	.193	.194	.458	.457
4	2	14169.	1.540	.683	.055	.063	.205	.213	.617	.596
4	3	17026.	1.539	.822	.085	.086	.222	.222	.653	.652
4	1	11422.	1.682	.505	-.015	-.015	.201	.201	.362	.362
4	2	15212.	1.683	.672	.025	.026	.177	.178	.466	.461
4	3	17868.	1.681	.791	.035	.038	.157	.160	.492	.483
5	1	7121.	1.294	.439	.104	.108	.324	.327	.534	.521
5	2	9620.	1.291	.596	.123	.133	.286	.294	.736	.712
5	3	11493.	1.295	.708	.141	.143	.310	.311	.883	.881
5	1	11370.	1.536	.550	.044	.048	.227	.231	.452	.436
5	2	13862.	1.534	.672	.055	.059	.234	.237	.525	.513
5	3	14501.	1.535	.702	.063	.068	.266	.270	.579	.564
5	4	17435.	1.537	.843	.085	.092	.267	.273	.647	.634
5	1	11350.	1.682	.502	-.016	-.012	.198	.202	.382	.366
5	2	14570.	1.679	.645	.011	.018	.151	.157	.461	.439
5	3	18170.	1.680	.805	.051	.059	.160	.168	.543	.524

TABLE E8 LOSS COEFFICIENTS OF BLADING WITH MINIMUM BEARING LOSSES

REDUCED TO STANDARD AIR IN ACCORDANCE WITH NASA METHOD
TOTAL INLET PRESSURE =14.7 PSIA,TOTAL INLET TEMPERATURE =518.7 DEG.R
GAMMA =1.4,SPECIFIC HEAT CP AT CONSTANT PRESSURE =0.24 BTU/(LBM,DF)

RUN	PI	SPEED RPM	PRESS. RATIO	U/CO	STATOR LOSS COEFFICIENT FOR AREA CALCULATION FLANGE	STATOR LOSS COEFFICIENT FOR AREA CALCULATION VENA.C	ROTOR LOSS COEFFICIENTS FOR AREAS FLANGE	ROTOR LOSS COEFFICIENTS FOR AREAS VENA.C	ROTOR LOSS COEFFICIENTS FOR EFFICIENCY FLANGE	ROTOR LOSS COEFFICIENTS FOR EFFICIENCY VENA.C
1	1	7114.	1.290	.441	.107	.104	.352	.350	.418	.430
1	2	9669.	1.293	.597	.133	.134	.325	.326	.365	.360
1	3	11423.	1.292	.706	.155	.135	.348	.331	.402	.473
1	1	11377.	1.536	.550	.037	.041	.245	.250	.088	.063
1	2	14010.	1.538	.677	.059	.065	.267	.272	.247	.226
1	3	16924.	1.533	.820	.070	.074	.253	.257	.238	.224
1	1	11359.	1.676	.504	-.009	-.007	.210	.211	.051	.042
1	2	15015.	1.678	.665	.031	.034	.185	.187	.139	.126
1	3	17828.	1.682	.788	.048	.053	.192	.196	.141	.124
2	1	7173.	1.291	.444	.066	.068	.291	.292	.415	.409
2	2	9696.	1.293	.599	.095	.095	.222	.222	.323	.321
2	3	11381.	1.295	.701	.113	.112	.285	.284	.461	.467
2	1	11394.	1.535	.551	.017	.020	.148	.151	.170	.154
2	2	13954.	1.536	.675	.039	.041	.138	.139	.220	.215
2	3	16986.	1.541	.819	.048	.051	.244	.246	.412	.404
2	1	11340.	1.685	.501	-.027	-.027	.203	.203	.211	.210
2	2	14809.	1.683	.655	.008	.010	.171	.173	.183	.176
2	3	16580.	1.687	.731	.021	.020	.211	.210	.210	.213
3	1	7132.	1.291	.442	.082	.081	.318	.317	.975	.976
3	2	9550.	1.292	.591	.114	.117	.209	.211	.998	.998
3	3	11530.	1.292	.713	.119	.116	.333	.330	.978	.976
3	1	11343.	1.529	.551	.027	.026	.148	.147	.706	.708
3	2	13901.	1.536	.672	.044	.048	.230	.234	.824	.817
3	3	17328.	1.537	.838	.071	.067	.241	.238	.899	.902
3	1	11393.	1.681	.504	-.037	-.035	.195	.196	.688	.683
3	2	14527.	1.681	.643	-.004	-.001	.268	.270	.831	.827
3	3	17809.	1.685	.786	.017	.017	.193	.193	.819	.820
4	1	7250.	1.294	.447	.088	.088	.311	.311	.430	.430
4	2	9753.	1.294	.601	.118	.118	.224	.224	.407	.407
4	3	11604.	1.295	.715	.126	.127	.288	.289	.524	.521
4	1	11534.	1.538	.557	.036	.036	.193	.194	.208	.206
4	2	14169.	1.540	.683	.055	.063	.205	.213	.368	.337
4	3	17026.	1.539	.822	.085	.086	.222	.222	.388	.387
4	1	11422.	1.682	.505	-.015	-.015	.201	.201	.174	.174
4	2	15212.	1.683	.672	.025	.026	.177	.178	.257	.250
4	3	17868.	1.681	.791	.035	.038	.157	.160	.276	.264
5	1	7121.	1.294	.439	.104	.108	.324	.327	.276	.259
5	2	9620.	1.291	.596	.123	.133	.286	.294	.370	.328
5	3	11493.	1.295	.708	.141	.143	.310	.311	.527	.523
5	1	11370.	1.536	.550	.044	.048	.227	.231	.203	.181
5	2	13862.	1.534	.672	.055	.059	.234	.237	.254	.238
5	3	14501.	1.535	.702	.063	.068	.266	.270	.318	.298
5	4	17435.	1.537	.843	.085	.092	.267	.273	.384	.366
5	1	11350.	1.682	.502	-.016	-.012	.198	.202	.197	.177
5	2	14570.	1.679	.645	.011	.018	.151	.157	.254	.224
5	3	18170.	1.680	.805	.051	.059	.160	.168	.339	.314

TABLE E9 LOSS COEFFICIENTS OF BLADING WITH MAXIMUM BEARING LOSSES

REDUCED TO STANDARD AIR IN ACCORDANCE WITH NASA METHOD
TOTAL INLET PRESSURE =14.7 PSIA,TOTAL INLET TEMPERATURE =518.7 DEG.R
GAMMA =1.4,SPECIFIC HEAT CP AT CONSTANT PRESSURE =0.24 BTU/(LBM,DF)

RUN	PT	SPEED	PRESS.	U/CO	STATOR LOSS COEFFICIENT		ROTOR LOSS COEFFICIENTS			
			RATIO		FOR AREA CALCULATION		FOR AREAS		FOR EFFICIENCY	
		RPM			FLANGE	VENA.C	FLANGE	VENA.C	FLANGE	VENA.C
1	1	7114.	1.290	.441	.107	.104	.352	.350	.311	.324
1	2	9669.	1.293	.597	.133	.134	.325	.326	.271	.266
1	3	11423.	1.292	.706	.155	.135	.348	.331	.313	.387
1	1	11377.	1.536	.550	.037	.041	.245	.250	.040	.014
1	2	14010.	1.538	.677	.059	.065	.267	.272	.197	.174
1	3	16924.	1.533	.820	.070	.074	.253	.257	.163	.148
1	1	11359.	1.676	.504	-.009	-.007	.210	.211	.016	.006
1	2	15015.	1.678	.665	.031	.034	.185	.187	.094	.080
1	3	17828.	1.682	.788	.048	.053	.192	.196	.076	.059
2	1	7173.	1.291	.444	.066	.068	.291	.292	.309	.303
2	2	9696.	1.293	.599	.095	.095	.222	.222	.226	.224
2	3	11381.	1.295	.701	.113	.112	.285	.284	.377	.384
2	1	11394.	1.535	.551	.017	.020	.148	.151	.124	.107
2	2	13954.	1.536	.675	.039	.041	.138	.139	.166	.161
2	3	16986.	1.541	.819	.048	.051	.244	.246	.347	.339
2	1	11340.	1.685	.501	-.027	-.027	.203	.203	.181	.179
2	2	14809.	1.683	.655	.008	.010	.171	.173	.141	.133
2	3	16580.	1.687	.731	.021	.020	.211	.210	.159	.163
3	1	7132.	1.291	.442	.082	.081	.318	.317	.950	.951
3	2	9550.	1.292	.591	.114	.117	.209	.211	.989	.988
3	3	11530.	1.292	.713	.119	.116	.333	.330	.991	.990
3	1	11343.	1.529	.551	.027	.026	.148	.147	.677	.680
3	2	13901.	1.536	.672	.044	.048	.230	.234	.798	.791
3	3	17328.	1.537	.838	.071	.067	.241	.238	.868	.873
3	1	11393.	1.681	.504	-.037	-.035	.195	.196	.667	.662
3	2	14527.	1.681	.643	-.004	-.001	.268	.270	.813	.809
3	3	17809.	1.685	.786	.017	.017	.193	.193	.790	.791
4	1	7250.	1.294	.447	.088	.088	.311	.311	.328	.326
4	2	9753.	1.294	.601	.118	.118	.224	.224	.313	.313
4	3	11604.	1.295	.715	.126	.127	.288	.289	.443	.439
4	1	11534.	1.538	.557	.036	.036	.193	.194	.161	.161
4	2	14169.	1.540	.683	.055	.063	.205	.213	.319	.289
4	3	17026.	1.539	.822	.085	.086	.222	.222	.321	.319
4	1	11422.	1.682	.505	-.015	-.015	.201	.201	.139	.141
4	2	15212.	1.683	.672	.025	.026	.177	.178	.215	.208
4	3	17868.	1.681	.791	.035	.038	.157	.160	.217	.204
5	1	7121.	1.294	.439	.104	.108	.324	.327	.157	.141
5	2	9620.	1.291	.596	.123	.133	.286	.294	.274	.229
5	3	11493.	1.295	.708	.141	.143	.310	.311	.446	.440
5	1	11370.	1.536	.550	.044	.048	.227	.231	.157	.135
5	2	13862.	1.534	.672	.055	.059	.234	.237	.203	.186
5	3	14501.	1.535	.702	.063	.068	.266	.270	.266	.247
5	4	17435.	1.537	.843	.085	.092	.267	.273	.311	.293
5	1	11350.	1.682	.502	-.016	-.012	.198	.202	.165	.144
5	2	14570.	1.679	.645	.011	.018	.151	.157	.213	.185
5	3	18170.	1.680	.805	.051	.059	.160	.168	.279	.254

AIR TESTS OF ICP RADIAL TURBINE

TABLE E10 OUTPUT DATA OBTAINED USING DISCHARGE PRESSURE SURVEY AND ITERATION FOR DISCHARGE TEMPERATURE

RUN 1 CLEARANCE - .027 RPM - 10162.

H2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.301	1.099	.349	506.3	48.5	188.8	48.3	.929	.137	551.6	538.1	537.5	42.94	-75.18	-27.12	83.7
1.82	1.301	1.099	.349	506.3	52.6	186.7	52.2	.938	.121	551.6	538.0	537.5	42.94	-73.78	-16.19	83.8
1.90	1.301	1.099	.349	506.3	59.1	187.5	58.6	.950	.097	551.6	537.9	537.5	42.94	-71.79	-2.71	83.8
2.10	1.301	1.099	.349	506.3	66.2	185.4	66.0	.905	.181	551.6	538.2	537.5	42.94	-69.14	11.82	82.9
2.34	1.302	1.099	.350	506.3	68.5	185.0	63.4	.822	.325	551.6	538.9	537.4	42.94	-69.96	11.30	81.1
2.60	1.302	1.100	.352	506.3	76.6	193.6	60.2	.756	.428	551.6	539.7	537.3	42.94	-71.89	-1.20	78.6
2.80	1.303	1.100	.353	506.3	125.9	188.4	86.8	.669	.553	551.6	541.0	537.3	42.94	-62.57	-14.48	73.4
2.88	1.301	1.099	.350	506.3	138.1	193.9	102.3	.698	.512	551.6	540.8	537.5	42.94	-58.17	-3.04	73.6
2.92	1.300	1.098	.348	506.3	141.9	186.1	103.4	.690	.524	551.6	540.8	537.6	42.94	-56.23	10.37	73.6
1.78	1.302	1.099	.350	506.3	56.5	191.0	56.4	.922	.150	551.6	538.0	537.4	42.94	-72.82	-21.62	83.4
1.82	1.301	1.099	.350	506.3	60.4	192.3	60.0	.943	.111	551.6	537.9	537.5	42.94	-71.82	-15.00	83.7
1.90	1.301	1.099	.349	506.3	57.1	185.2	56.7	.943	.111	551.6	537.9	537.5	42.94	-72.16	-1.50	83.8
2.10	1.301	1.099	.350	506.3	69.0	183.1	69.0	.920	.154	551.6	538.0	537.5	42.94	-67.86	17.00	83.1
2.34	1.302	1.100	.351	506.3	68.9	179.2	65.2	.823	.322	551.6	538.7	537.4	42.94	-68.67	18.67	81.3
2.60	1.303	1.100	.353	506.3	77.6	185.9	61.1	.743	.448	551.6	539.7	537.3	42.94	-70.80	7.73	78.6
2.80	1.306	1.103	.357	506.3	135.5	188.8	99.5	.666	.556	551.6	540.7	537.0	42.94	-58.22	-4.61	73.0
2.88	1.302	1.099	.351	506.3	135.3	190.2	103.6	.709	.497	551.6	540.4	537.4	42.94	-56.99	9.46	74.5
2.92	1.301	1.099	.349	506.3	138.9	187.5	108.3	.721	.480	551.6	540.3	537.5	42.94	-54.72	19.33	74.9

MASS FLOW RATE (VENA CONTRACTA) -- 1.260

MASS FLOW RATE AVERAGED OUTPUT

	W2	W21H	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	188.8	245.3	.770	.408	.611	73.1	78.8
RIGHT SIDE	185.7	241.8	.768	.410	.634	72.9	79.1

RUN 1 CLEARANCE - .027 RPM - 17869.

H2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.545	1.276	.546	540.0	63.6	258.7	21.6	1.688	-1.850	553.9	516.2	519.8	-65.00	-85.22	-30.33	91.2
1.82	1.545	1.276	.545	540.0	76.9	251.9	35.9	1.663	-1.765	553.9	516.5	519.8	-65.00	-81.82	-26.03	90.7
1.90	1.545	1.277	.546	540.0	102.2	235.6	57.8	1.636	-1.678	553.9	516.9	519.7	-65.00	-75.81	-13.50	89.4
2.10	1.545	1.276	.546	540.0	153.7	217.3	90.7	1.349	-.819	553.9	518.0	519.8	-65.00	-65.31	5.06	86.1
2.34	1.544	1.276	.545	540.0	168.8	229.2	91.9	1.082	-.170	553.9	519.3	519.9	-65.00	-66.36	10.99	83.8
2.60	1.544	1.276	.545	540.0	174.6	272.0	94.6	.945	.107	553.9	520.7	519.9	-65.00	-69.65	2.98	81.5
2.80	1.543	1.275	.544	540.0	231.1	299.0	142.3	.870	.244	553.9	522.4	520.0	-65.00	-61.59	-7.08	76.2
2.88	1.538	1.271	.541	540.0	251.9	311.4	168.5	.912	.168	553.9	522.1	520.4	-65.00	-57.24	.07	75.9
2.92	1.534	1.267	.538	540.0	257.1	309.8	176.0	.954	.091	553.9	521.7	520.8	-65.00	-55.39	10.69	76.7
1.78	1.546	1.279	.549	538.2	43.9	259.9	.0	1.903	-2.623	554.1	515.6	519.7	-65.27	-90.00	-15.55	92.2
1.82	1.546	1.279	.549	538.2	46.4	272.7	1.6	1.623	-1.634	554.1	515.9	519.7	-65.27	-89.66	-20.30	91.8
1.90	1.546	1.279	.549	538.2	61.3	277.8	29.0	1.485	-1.206	554.1	516.2	519.7	-65.27	-84.01	-19.85	91.1
2.10	1.546	1.279	.549	538.2	119.3	239.9	75.1	1.405	-.973	554.1	517.4	519.7	-65.27	-71.76	4.19	88.1
2.34	1.545	1.278	.549	538.2	158.5	236.9	99.7	1.189	-.413	554.1	518.4	519.7	-65.27	-65.10	15.89	85.3
2.60	1.546	1.279	.549	538.2	179.1	271.4	112.7	.992	.017	554.1	519.9	519.7	-65.27	-65.46	11.60	82.3
2.80	1.544	1.277	.548	538.2	217.4	306.7	148.8	.941	.114	554.1	520.9	519.9	-65.27	-60.97	6.05	79.0
2.88	1.542	1.275	.547	538.2	235.1	313.2	169.1	.974	.052	554.1	520.6	520.1	-65.27	-57.32	13.19	78.8
2.92	1.540	1.274	.545	538.2	238.9	313.8	175.9	1.008	-.017	554.1	520.2	520.3	-65.27	-55.92	19.65	79.4

MASS FLOW RATE (VENA CONTRACTA) -- 1.608

MASS FLOW RATE AVERAGED OUTPUT

	W2	W21H	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	269.5	276.5	.975	.050	.931	73.5	81.4
RIGHT SIDE	278.3	270.3	1.030	-.060	.914	73.3	83.1

RUN 1 CLEARANCE - .027 RPM - 18952.

H2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.699	1.330	.519	613.1	108.2	230.7	59.9	1.357	-.842	554.8	511.7	513.7	-58.47	-74.96	-14.33	89.1
1.82	1.699	1.330	.519	613.1	120.6	226.1	70.9	1.343	-.804	554.8	511.9	513.7	-58.47	-71.73	-8.85	88.7
1.90	1.699	1.330	.519	613.1	136.6	224.6	82.6	1.260	-.587	554.8	512.2	513.7	-58.47	-68.43	-2.66	87.8
2.10	1.698	1.329	.519	613.1	161.0	234.2	97.4	1.083	-.173	554.8	513.2	513.8	-58.47	-65.44	4.74	86.0
2.34	1.698	1.329	.519	613.1	165.7	271.1	106.1	1.009	-.018	554.8	513.7	513.8	-58.47	-66.97	8.00	85.2
2.60	1.700	1.331	.520	613.1	170.4	312.7	107.2	.928	.139	554.8	515.0	513.6	-58.47	-69.95	3.02	83.3
2.80	1.700	1.331	.520	613.1	244.9	330.5	157.4	.824	.321	554.8	517.9	513.6	-58.47	-61.57	-11.76	76.7
2.88	1.694	1.327	.517	613.1	263.4	342.1	182.3	.865	.252	554.8	517.3	514.1	-58.47	-57.80	-2.62	76.8
2.92	1.689	1.322	.514	613.1	268.2	386.7	219.7	1.021	-.043	554.8	514.1	514.6	-58.47	-55.38	8.47	81.0
1.78	1.698	1.333	.524	610.1	79.4	274.2	43.0	1.237	-.529	555.1	511.6	513.8	-59.03	-80.97	-23.36	89.8
1.82	1.699	1.333	.524	610.1	95.8	255.5	57.4	1.255	-.576	555.1	511.8	513.7	-59.03	-77.02	-13.83	89.3
1.90	1.698	1.333	.524	610.1	114.9	243.7	74.2	1.263	-.596	555.1	512.0	513.8	-59.03	-72.28	-3.27	88.7
2.10	1.697	1.332	.523	610.1	146.7	238.5	99.3	1.201	-.443	555.1	512.5	513.9	-59.03	-65.40	12.67	87.4
2.34	1.698	1.332	.523	610.1	164.0	263.6	109.7	1.033	-.068	555.1	513.5	513.8	-59.03	-65.40	14.29	85.6
2.60	1.699	1.334	.524	610.1	179.3	299.9	117.6	.924	.146	555.1	515.0	513.7	-59.03	-66.91	10.67	83.1
2.80	1.699	1.333	.524	610.1	224.9	338.4	156.2	.876	.232	555.1	516.6	513.7	-59.03	-62.50	.65	79.2
2.88	1.696	1.331	.522	610.1	247.0	343.2	181.8	.910	.172	555.1	516.1	514.0	-59.03	-58.01	10.25	79.1
2.92	1.693	1.329	.521	610.1	253.5	345.8	193.1	.947	.103	555.1	515.4	514.2	-59.03	-56.07	17.58	79.8

MASS FLOW RATE (VENA CONTRACTA) -- 1.927

MASS FLOW RATE AVERAGED OUTPUT

	W2	W21H	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	300.9	324.0	.929	.137	1.087	78.5	82.7
RIGHT SIDE	298.4	312.5	.955	.088	1.082	78.6	83.7

TABLE E10 (CONTINUED)

RUN 2 CLEARANCE - .042 RPM - 7530.

R2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.303	1.072	.256	542.2	132.9	241.0	92.3	.984	.032	547.2	540.7	540.5	67.30	-67.49	-18.71	70.7
1.82	1.302	1.071	.254	542.2	142.0	246.5	99.3	1.023	-.047	547.2	540.4	540.6	67.30	-66.24	-8.74	71.1
1.90	1.301	1.071	.252	542.2	149.0	252.2	105.3	1.060	-.124	547.2	540.2	540.7	67.30	-65.31	2.00	71.5
2.10	1.300	1.070	.250	542.2	136.1	241.9	98.9	1.022	-.045	547.2	540.7	540.9	67.30	-65.87	19.73	71.2
2.34	1.301	1.071	.252	542.2	100.9	215.8	81.2	.875	.234	547.2	542.0	540.7	67.30	-67.89	24.71	69.6
2.60	1.302	1.071	.254	542.2	70.2	186.0	68.5	.717	.487	547.2	543.4	540.6	67.30	-68.40	23.81	67.0
2.80	1.303	1.072	.256	542.2	92.7	169.5	80.2	.591	.650	547.2	544.9	540.5	67.30	-61.79	-21.97	62.5
2.88	1.302	1.071	.254	542.2	102.2	161.7	85.3	.572	.673	547.2	545.1	540.6	67.30	-58.15	-8.35	61.9
2.92	1.301	1.070	.252	542.2	101.6	156.0	83.4	.562	.685	547.2	545.1	540.7	67.30	-57.67	4.06	62.0
1.78	1.302	1.071	.254	542.2	128.9	244.6	84.6	.996	.008	547.2	540.7	540.6	67.30	-69.77	-20.50	71.2
1.82	1.302	1.071	.253	542.2	137.3	248.5	93.3	1.023	-.046	547.2	540.5	540.7	67.30	-67.96	-13.82	71.3
1.90	1.300	1.070	.251	542.2	143.7	251.3	99.5	1.056	-.116	547.2	540.3	540.8	67.30	-66.69	-3.12	71.6
2.10	1.299	1.069	.249	542.2	134.2	242.2	94.3	1.030	-.061	547.2	540.7	540.9	67.30	-67.10	14.39	71.4
2.34	1.300	1.070	.250	542.2	102.8	220.3	78.3	.903	.184	547.2	541.8	540.8	67.30	-69.19	19.52	70.1
2.60	1.301	1.071	.253	542.2	73.7	196.3	68.3	.764	.417	547.2	543.0	540.7	67.30	-69.65	19.76	67.9
2.80	1.302	1.071	.253	542.2	82.0	186.8	77.5	.657	.568	547.2	544.5	540.7	67.30	-65.50	-17.67	64.0
2.88	1.301	1.071	.252	542.2	93.2	176.7	85.4	.633	.600	547.2	544.6	540.7	67.30	-61.09	-3.91	63.6
2.92	1.301	1.070	.252	542.2	97.5	170.7	89.3	.623	.612	547.2	544.5	540.7	67.30	-58.45	10.30	63.6

MASS FLOW RATE (VENA CONTRACTA) -- 1.379

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	212.0	255.8	.829	.313	.706	64.1	68.0
RIGHT SIDE	217.1	254.2	.854	.270	.699	64.2	68.6

RUN 2 CLEARANCE - .042 RPM - 10178.

R2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.301	1.095	.337	510.6	56.6	193.7	55.1	1.064	-.132	549.9	536.1	536.4	43.93	-73.48	-19.72	85.1
1.82	1.302	1.096	.338	510.6	60.1	190.3	58.7	1.061	-.126	549.9	536.1	536.4	43.93	-72.01	-9.57	85.0
1.90	1.302	1.096	.338	510.6	65.0	191.7	63.9	1.066	-.136	549.9	536.0	536.4	43.93	-70.51	-.27	85.0
2.10	1.302	1.096	.338	510.6	72.7	194.8	72.7	1.015	-.030	549.9	536.3	536.3	43.93	-68.09	8.46	84.1
2.34	1.302	1.096	.339	510.6	74.9	192.1	71.0	.898	.193	549.9	537.0	536.3	43.93	-68.29	8.10	82.1
2.60	1.303	1.097	.340	510.6	77.5	191.4	59.4	.785	.383	549.9	538.1	536.2	43.93	-71.93	-1.13	79.2
2.80	1.304	1.098	.342	510.6	131.9	192.9	91.9	.696	.516	549.9	539.4	536.1	43.93	-61.55	-20.94	73.6
2.88	1.302	1.096	.339	510.6	147.4	191.2	105.3	.703	.506	549.9	539.3	536.3	43.93	-56.58	-9.68	73.4
2.92	1.301	1.095	.336	510.6	156.0	191.4	115.9	.733	.463	549.9	539.1	536.5	43.93	-52.74	3.72	73.8
1.78	1.301	1.097	.343	508.4	58.1	211.2	57.4	1.005	-.010	550.1	536.3	536.3	43.32	-74.23	-33.50	84.5
1.82	1.301	1.097	.342	508.4	55.5	206.9	54.9	1.004	-.007	550.1	536.4	536.3	43.32	-74.60	-28.66	84.5
1.90	1.301	1.097	.343	508.4	64.3	199.3	63.7	1.017	-.034	550.1	536.3	536.3	43.32	-71.36	-11.43	84.5
2.10	1.301	1.097	.343	508.4	66.0	195.9	65.9	.990	.020	550.1	536.4	536.3	43.32	-70.33	4.51	84.1
2.34	1.302	1.097	.344	508.4	67.2	192.1	64.8	.892	.204	550.1	537.1	536.3	43.32	-70.28	9.46	82.3
2.60	1.303	1.098	.345	508.4	71.5	197.3	56.3	.789	.377	550.1	538.2	536.1	43.32	-73.42	-2.28	79.4
2.80	1.303	1.098	.346	508.4	119.7	201.7	87.3	.722	.479	550.1	539.3	536.1	43.32	-64.36	-15.36	74.8
2.85	1.302	1.098	.344	508.4	144.2	193.0	105.5	.705	.503	550.1	539.4	536.2	43.32	-56.87	-4.33	73.5
2.92	1.301	1.096	.341	508.4	152.2	186.1	112.8	.715	.488	550.1	539.2	536.4	43.32	-52.69	9.36	73.9

MASS FLOW RATE (VENA CONTRACTA) -- 1.297

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	192.3	234.0	.822	.325	.653	73.5	79.9
RIGHT SIDE	196.3	239.9	.818	.330	.619	73.6	79.9

RUN 2 CLEARANCE - .042 RPM - 11952.

R2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.302	1.122	.427	475.5	58.7	156.1	39.8	1.113	-.239	553.2	535.0	535.3	-14.85	-75.25	-10.24	88.4
1.82	1.302	1.122	.427	475.5	63.3	155.8	44.1	1.101	-.213	553.2	535.0	535.3	-14.85	-73.55	-6.00	88.2
1.90	1.302	1.122	.427	475.5	72.0	156.1	50.2	1.056	-.116	553.2	535.2	535.3	-14.85	-71.23	-1.51	87.6
2.10	1.303	1.123	.428	475.5	87.1	165.6	60.1	.962	.074	553.2	535.5	535.3	-14.85	-68.73	2.00	86.2
2.34	1.303	1.122	.428	475.5	99.5	173.7	63.1	.877	.231	553.2	536.1	535.3	-14.85	-68.68	6.51	84.4
2.60	1.303	1.123	.428	475.5	106.3	185.4	54.1	.792	.372	553.2	537.0	535.3	-14.85	-73.03	2.91	81.9
2.80	1.304	1.123	.429	475.5	156.5	212.5	101.4	.765	.415	553.2	537.9	535.2	-14.85	-61.48	-16.23	76.9
2.88	1.301	1.121	.426	475.5	177.6	220.5	126.0	.810	.344	553.2	537.6	535.5	-14.85	-55.14	-6.76	76.7
2.92	1.299	1.119	.421	475.5	190.1	217.7	136.7	.838	.298	553.2	537.5	535.8	-14.85	-51.09	3.73	76.7
1.78	1.302	1.124	.433	473.2	55.1	158.4	34.5	1.034	-.069	553.4	535.2	535.3	-16.41	-77.41	-10.46	88.0
1.82	1.302	1.124	.432	473.2	58.1	162.2	38.9	1.041	-.084	553.4	535.2	535.4	-16.41	-76.13	-9.46	88.0
1.90	1.302	1.123	.432	473.2	65.9	155.5	45.4	1.039	-.080	553.4	535.3	535.4	-16.41	-73.01	1.50	87.7
2.10	1.302	1.123	.432	473.2	80.0	159.1	57.6	.999	.002	553.4	535.4	535.4	-16.41	-68.79	13.12	87.0
2.34	1.302	1.124	.432	473.2	92.6	169.1	62.7	.905	.180	553.4	535.9	535.3	-16.41	-68.24	16.24	85.3
2.60	1.302	1.124	.433	473.2	103.1	186.0	62.4	.824	.321	553.4	536.7	535.3	-16.41	-70.41	12.06	82.9
2.80	1.304	1.125	.435	473.2	142.7	220.5	98.4	.796	.366	553.4	537.6	535.2	-16.41	-63.49	-7.62	78.6
2.88	1.301	1.123	.431	473.2	167.9	227.8	124.8	.832	.308	553.4	537.4	535.4	-16.41	-56.79	-2.29	77.9
2.92	1.301	1.122	.430	473.2	181.5	218.2	134.9	.836	.301	553.4	537.3	535.5	-16.41	-51.80	10.19	77.5

MASS FLOW RATE (VENA CONTRACTA) -- 1.216

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	191.7	230.6	.831	.309	.632	71.7	82.0
RIGHT SIDE	194.2	228.2	.851	.276	.627	71.8	82.8

TABLE E10 (CONTINUED)

RUN 2 CLEARANCE - .042 RPM - 12080.

H2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.591	1.194	.365	660.8	101.9	270.0	83.5	.743	.447	546.7	526.6	521.7	53.54	-71.98	-12.53	76.7
1.82	1.592	1.194	.366	660.8	110.6	271.6	93.2	.749	.438	546.7	526.5	521.6	53.54	-69.93	-4.35	76.6
1.90	1.592	1.194	.366	660.8	113.8	277.0	95.9	.761	.421	546.7	526.3	521.6	53.54	-69.76	2.00	76.8
2.10	1.592	1.194	.366	660.8	109.7	275.5	99.2	.743	.449	546.7	526.8	521.6	53.54	-68.89	13.02	76.2
2.34	1.593	1.195	.367	660.8	91.3	263.2	89.9	.683	.534	546.7	528.1	521.5	53.54	-70.83	17.50	74.6
2.60	1.596	1.197	.369	660.8	85.3	267.2	82.0	.639	.591	546.7	529.9	521.3	53.54	-72.12	-4.46	72.1
2.80	1.596	1.197	.369	660.8	153.6	258.8	124.2	.581	.662	546.7	532.1	521.2	53.54	-61.31	-24.79	67.2
2.88	1.592	1.194	.366	660.8	165.2	251.8	133.6	.578	.666	546.7	532.1	521.6	53.54	-57.94	-8.13	67.2
2.92	1.589	1.192	.363	660.8	165.2	245.1	133.0	.574	.670	546.7	532.0	521.9	53.54	-57.13	4.69	67.5
1.78	1.590	1.196	.370	657.7	106.4	281.9	81.0	.762	.420	547.0	526.4	521.6	53.12	-73.30	-11.62	76.9
1.82	1.591	1.197	.371	657.7	110.0	281.2	88.3	.758	.426	547.0	526.5	521.5	53.12	-71.69	-8.29	76.7
1.90	1.591	1.196	.371	657.7	108.5	279.9	89.5	.752	.434	547.0	526.6	521.6	53.12	-71.35	-3.22	76.6
2.10	1.591	1.197	.371	657.7	103.3	275.0	92.5	.727	.471	547.0	527.2	521.5	53.12	-70.34	7.29	75.9
2.34	1.593	1.198	.372	657.7	83.5	260.2	81.9	.666	.556	547.0	528.5	521.4	53.12	-71.64	13.48	74.4
2.60	1.594	1.199	.374	657.7	76.3	257.7	70.9	.612	.625	547.0	530.5	521.2	53.12	-74.04	-1.80	71.6
2.80	1.596	1.201	.375	657.7	145.3	271.1	123.5	.599	.641	547.0	531.9	521.0	53.12	-62.90	-19.21	67.8
2.88	1.594	1.199	.373	657.7	168.0	261.2	141.9	.589	.653	547.0	531.9	521.2	53.12	-57.10	-5.02	67.2
2.92	1.591	1.197	.371	657.7	173.9	250.8	146.8	.582	.661	547.0	531.7	521.5	53.12	-54.18	9.78	67.4

MASS FLOW RATE (VENA CONTRACTA) -- 1.904

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	264.9	404.4	.655	.571	.878	71.6	72.5
RIGHT SIDE	266.8	411.7	.648	.580	.846	71.6	72.2

RUN 2 CLEARANCE - .042 RPM - 14794.

H2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.552	1.204	.406	622.6	82.8	228.2	77.8	1.092	-.193	550.8	521.7	522.4	3.39	-70.05	-12.53	88.3
1.82	1.552	1.203	.406	622.6	85.0	230.3	80.9	1.113	-.238	550.8	521.6	522.4	3.39	-69.44	-6.70	88.5
1.90	1.552	1.203	.406	622.6	86.4	237.6	82.1	1.097	-.204	550.8	521.6	522.4	3.39	-69.77	-4.19	88.4
2.10	1.552	1.204	.407	622.6	101.1	249.8	90.6	.999	.003	550.8	522.4	522.3	3.39	-68.74	-6.46	86.9
2.34	1.552	1.204	.407	622.6	107.5	251.0	85.6	.911	.171	550.8	523.4	522.3	3.39	-70.05	1.16	85.2
2.60	1.554	1.205	.408	622.6	107.7	268.7	75.6	.856	.268	550.8	524.5	522.2	3.39	-73.66	1.16	83.6
2.80	1.556	1.207	.410	622.6	189.4	312.4	149.7	.828	.314	550.8	525.7	521.9	3.39	-61.36	-26.10	78.5
2.88	1.550	1.203	.405	622.6	226.2	301.6	178.7	.841	.293	550.8	525.6	522.5	3.39	-53.66	-9.46	77.4
2.92	1.545	1.198	.401	622.6	237.0	292.7	185.7	.858	.263	550.8	525.5	523.0	3.39	-50.62	3.45	77.5
1.78	1.550	1.206	.411	619.4	81.8	216.1	69.5	.973	.053	551.1	522.7	522.4	1.69	-71.24	-12.58	87.1
1.82	1.550	1.206	.411	619.4	82.5	225.0	73.7	1.007	-.015	551.1	522.5	522.5	1.69	-70.87	-10.29	87.5
1.90	1.551	1.206	.412	619.4	86.1	232.9	79.6	1.025	-.051	551.1	522.2	522.4	1.69	-70.01	-4.56	87.7
2.10	1.550	1.206	.411	619.4	95.6	246.2	87.3	1.004	-.007	551.1	522.5	522.5	1.69	-69.23	1.50	87.2
2.34	1.552	1.207	.413	619.4	108.1	237.1	85.4	.881	.225	551.1	523.7	522.3	1.69	-68.89	10.36	84.9
2.60	1.553	1.208	.414	619.4	114.1	256.2	78.4	.818	.330	551.1	524.9	522.2	1.69	-72.18	6.31	82.8
2.80	1.556	1.210	.416	619.4	177.2	309.7	142.6	.830	.311	551.1	525.5	521.9	1.69	-62.58	-13.05	79.3
2.88	1.553	1.208	.414	619.4	211.5	310.9	173.2	.846	.285	551.1	525.3	522.2	1.69	-56.14	-5.44	78.4
2.92	1.549	1.205	.411	619.4	228.9	297.0	186.1	.858	.263	551.1	525.1	522.5	1.69	-51.20	8.70	78.2

MASS FLOW RATE (VENA CONTRACTA) -- 1.799

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	274.7	311.0	.883	.220	.927	78.6	83.1
RIGHT SIDE	271.5	312.5	.869	.245	.919	78.6	83.1

RUN 2 CLEARANCE - .042 RPM - 17972.

H2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.553	1.281	.546	543.7	67.5	256.6	24.9	1.606	-1.579	556.3	518.1	521.4	-64.91	-84.44	-28.65	90.8
1.82	1.553	1.281	.547	543.7	81.0	244.3	40.3	1.669	-1.785	556.3	518.3	521.4	-64.91	-80.51	-19.87	90.3
1.90	1.554	1.281	.547	543.7	106.0	230.5	61.1	1.619	-1.620	556.3	518.7	521.4	-64.91	-74.63	-8.63	89.1
2.10	1.553	1.281	.546	543.7	151.8	216.7	89.2	1.322	-.748	556.3	519.8	521.4	-64.91	-65.67	7.26	86.1
2.34	1.552	1.280	.546	543.7	167.3	230.8	90.6	1.061	-.125	556.3	521.1	521.6	-64.91	-66.88	11.14	83.8
2.60	1.552	1.280	.546	543.7	175.2	267.5	91.3	.924	.147	556.3	522.6	521.5	-64.91	-70.05	5.41	81.2
2.80	1.551	1.279	.545	543.7	233.4	293.1	136.5	.835	.302	556.3	524.8	521.6	-64.91	-62.23	-7.56	75.3
2.88	1.546	1.275	.542	543.7	256.7	306.1	166.4	.882	.222	556.3	524.4	522.2	-64.91	-57.07	-.55	75.0
2.92	1.541	1.271	.539	543.7	263.5	308.3	177.7	.929	.137	556.3	523.9	522.6	-64.91	-54.81	9.12	75.8
1.78	1.555	1.284	.551	541.9	41.3	299.2	-.1	1.410	-.987	556.4	517.6	521.3	-65.18	89.97	-32.27	91.7
1.82	1.555	1.284	.551	541.9	45.4	298.4	9.4	1.386	-.922	556.4	517.8	521.3	-65.18	-88.19	-30.50	91.4
1.90	1.555	1.284	.551	541.9	71.4	265.3	37.2	1.434	-1.057	556.4	518.3	521.2	-65.18	-81.93	-14.79	90.3
2.10	1.556	1.284	.551	541.9	122.2	235.6	79.5	1.391	-.935	556.4	519.0	521.2	-65.18	-70.27	8.66	88.0
2.34	1.554	1.283	.550	541.9	156.1	236.6	97.4	1.155	-.333	556.4	520.2	521.4	-65.18	-65.69	16.83	85.2
2.60	1.555	1.284	.551	541.9	174.0	270.4	106.2	.966	.067	556.4	521.8	521.3	-65.18	-66.88	12.29	82.2
2.80	1.555	1.284	.551	541.9	220.2	309.4	145.6	.888	.211	556.4	523.4	521.2	-65.18	-61.92	.61	77.5
2.88	1.552	1.281	.549	541.9	242.1	314.3	170.0	.922	.150	556.4	523.1	521.6	-65.18	-57.26	8.75	77.2
2.92	1.548	1.278	.546	541.9	248.8	316.0	180.7	.969	.060	556.4	522.5	521.9	-65.18	-55.12	15.95	78.0

MASS FLOW RATE (VENA CONTRACTA) -- 1.640

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	265.9	279.9	.950	.098	.913	71.0	81.0
RIGHT SIDE	278.3	281.6	.989	.023	.909	70.7	82.6

TABLE E10 (CONTINUED)

RUN 2 CLEARANCE - .042 RPM - 12162.

R2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.709	1.187	.303	748.7	188.7	357.8	135.7	1.009	-.017	550.0	528.1	528.3	61.40	-67.70	-12.87	77.4
1.82	1.707	1.185	.301	748.7	194.0	359.9	140.5	1.026	-.053	550.0	527.9	528.4	61.40	-67.02	-5.14	77.6
1.90	1.706	1.184	.301	748.7	196.3	362.5	142.7	1.038	-.078	550.0	527.8	528.5	61.40	-66.83	3.87	77.8
2.10	1.705	1.184	.300	748.7	167.7	340.5	126.9	.966	.066	550.0	529.3	528.6	61.40	-68.11	18.84	77.0
2.34	1.707	1.186	.302	748.7	129.2	313.9	107.4	.857	.265	550.0	531.4	528.4	61.40	-69.99	27.63	75.5
2.60	1.709	1.187	.303	748.7	85.1	294.7	83.1	.745	.444	550.0	534.0	528.2	61.40	-73.63	13.33	73.2
2.80	1.712	1.189	.305	748.7	156.1	303.6	145.9	.691	.523	550.0	536.3	527.9	61.40	-61.27	-26.86	68.6
2.88	1.708	1.186	.302	748.7	177.2	302.0	165.4	.701	.508	550.0	536.1	528.3	61.40	-56.80	-12.30	68.5
2.92	1.705	1.184	.300	748.7	179.3	294.8	167.4	.703	.506	550.0	536.0	528.6	61.40	-55.39	3.62	68.8
1.78	1.707	1.185	.301	748.7	194.2	367.8	133.9	1.042	-.086	550.0	527.6	528.4	61.40	-68.65	-11.19	78.0
1.82	1.706	1.184	.301	748.7	197.0	368.5	136.8	1.052	-.107	550.0	527.5	528.5	61.40	-68.20	-6.27	78.1
1.90	1.703	1.183	.299	748.7	192.5	362.6	136.1	1.046	-.094	550.0	527.8	528.7	61.40	-67.95	1.50	78.0
2.10	1.704	1.183	.299	748.7	173.7	347.8	128.7	.990	.019	550.0	528.9	528.7	61.40	-68.29	14.00	77.4
2.34	1.707	1.185	.301	748.7	135.1	320.3	108.2	.881	.223	550.0	531.0	528.5	61.40	-70.26	22.87	75.9
2.60	1.709	1.187	.303	748.7	90.7	315.9	85.7	.786	.383	550.0	533.4	528.2	61.40	-74.27	1.50	73.8
2.80	1.710	1.187	.304	748.7	152.0	307.8	143.2	.703	.506	550.0	536.2	528.1	61.40	-62.28	-21.76	69.0
2.88	1.707	1.185	.301	748.7	170.3	303.2	161.1	.712	.492	550.0	535.8	528.4	61.40	-57.92	-5.85	69.1
2.92	1.705	1.184	.300	748.7	172.8	297.1	164.3	.717	.487	550.0	535.5	528.6	61.40	-56.42	7.80	69.5

MASS FLOW RATE (VENA CONTRACTA) -- 2.235

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	321.4	388.6	.827	.316	1.041	72.4	73.8
RIGHT SIDE	328.0	387.6	.846	.284	1.062	72.5	74.2

RUN 2 CLEARANCE - .042 RPM - 15882.

R2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.705	1.253	.405	690.3	101.9	277.2	101.7	.995	.010	557.0	522.4	522.2	13.35	-68.47	-15.22	87.1
1.82	1.704	1.253	.405	690.3	102.1	279.3	102.0	.999	.002	557.0	522.3	522.3	13.35	-68.58	-11.73	87.1
1.90	1.704	1.253	.404	690.3	101.5	283.7	101.3	.997	.006	557.0	522.4	522.3	13.35	-69.08	-7.23	87.1
2.10	1.704	1.253	.405	690.3	104.9	291.8	102.9	.952	.094	557.0	523.0	522.3	13.35	-69.36	-2.49	86.2
2.34	1.705	1.254	.405	690.3	104.7	290.7	93.6	.868	.247	557.0	524.6	522.2	13.35	-71.21	2.00	84.4
2.60	1.706	1.254	.406	690.3	109.1	312.9	88.5	.830	.311	557.0	525.8	522.1	13.35	-73.57	-3.24	82.7
2.80	1.711	1.258	.409	690.3	202.5	360.7	173.2	.823	.323	557.0	526.8	521.7	13.35	-61.30	-27.74	78.2
2.88	1.700	1.250	.402	690.3	248.8	332.2	203.8	.813	.339	557.0	527.3	522.7	13.35	-52.15	-5.31	76.5
2.92	1.695	1.246	.399	690.3	255.5	326.4	207.3	.817	.332	557.0	527.4	523.1	13.35	-50.58	2.77	76.4
1.78	1.703	1.256	.409	687.5	94.4	279.0	93.3	.939	.119	557.3	523.2	522.3	12.12	-70.46	-19.64	86.3
1.82	1.703	1.256	.409	687.5	98.1	284.8	97.8	.964	.070	557.3	522.8	522.3	12.12	-69.92	-15.07	86.7
1.90	1.703	1.256	.409	687.5	102.7	292.2	102.5	.974	.052	557.3	522.7	522.3	12.12	-69.47	-11.00	86.8
2.10	1.704	1.256	.409	687.5	106.3	285.9	103.3	.918	.158	557.3	523.5	522.2	12.12	-68.81	-.31	85.6
2.34	1.705	1.257	.410	687.5	101.7	279.2	87.7	.829	.313	557.3	525.1	522.1	12.12	-71.69	5.21	83.8
2.60	1.706	1.258	.411	687.5	108.3	306.3	84.7	.802	.356	557.3	526.4	522.0	12.12	-73.95	-1.04	82.0
2.80	1.711	1.261	.413	687.5	188.1	356.7	162.9	.822	.325	557.3	526.7	521.6	12.12	-62.82	-15.15	79.0
2.88	1.707	1.258	.411	687.5	230.5	347.6	195.9	.814	.337	557.3	527.0	521.9	12.12	-55.69	-6.28	77.1
2.92	1.701	1.254	.407	687.5	245.3	331.1	206.2	.822	.324	557.3	526.8	522.5	12.12	-51.48	8.47	77.2

MASS FLOW RATE (VENA CONTRACTA) -- 2.093

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	315.7	368.8	.856	.267	1.059	80.0	82.3
RIGHT SIDE	315.6	375.1	.841	.292	1.034	79.9	82.3

RUN 2 CLEARANCE - .042 RPM - 17775.

R2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.706	1.301	.474	649.2	108.7	218.2	74.4	.968	.062	561.1	521.4	521.1	-38.51	-70.06	-6.67	87.5
1.82	1.705	1.301	.474	649.2	109.8	222.7	78.2	.983	.033	561.1	521.3	521.1	-38.51	-69.44	-2.67	87.6
1.90	1.706	1.301	.474	649.2	110.6	232.3	79.6	.973	.053	561.1	521.4	521.1	-38.51	-69.97	-.30	87.5
2.10	1.707	1.302	.474	649.2	120.5	264.4	92.0	.953	.093	561.1	521.7	521.0	-38.51	-69.63	.05	86.8
2.34	1.708	1.303	.475	649.2	134.8	296.1	107.7	.938	.120	561.1	522.0	520.9	-38.51	-68.68	4.86	86.0
2.60	1.709	1.304	.476	649.2	140.6	316.8	99.4	.866	.250	561.1	523.6	520.8	-38.51	-71.71	2.51	83.8
2.80	1.713	1.307	.478	649.2	226.6	345.9	163.0	.791	.375	561.1	526.4	520.5	-38.51	-61.89	-21.72	77.1
2.88	1.707	1.302	.474	649.2	265.0	348.0	198.1	.810	.344	561.1	526.2	521.0	-38.51	-55.30	-12.24	75.9
2.92	1.696	1.294	.469	649.2	278.9	339.8	210.5	.843	.289	561.1	525.8	521.9	-38.51	-51.73	2.65	76.5
1.78	1.704	1.303	.478	646.2	104.7	219.4	68.7	.927	.141	561.4	521.9	521.2	-39.54	-71.75	-6.69	87.1
1.82	1.704	1.303	.478	646.2	109.4	219.0	75.1	.941	.114	561.4	521.8	521.2	-39.54	-69.93	-1.68	87.2
1.90	1.704	1.303	.478	646.2	117.3	216.7	82.9	.940	.117	561.4	521.8	521.2	-39.54	-67.50	6.89	87.0
2.10	1.704	1.303	.478	646.2	124.3	242.1	92.4	.931	.134	561.4	522.0	521.2	-39.54	-67.57	11.02	86.6
2.34	1.706	1.304	.478	646.2	138.9	270.8	103.6	.892	.204	561.4	522.7	521.1	-39.54	-67.51	11.86	85.3
2.60	1.707	1.305	.479	646.2	147.0	303.5	108.5	.867	.248	561.4	523.5	520.9	-39.54	-69.05	12.18	83.9
2.80	1.711	1.308	.481	646.2	208.3	345.2	154.8	.811	.342	561.4	525.7	520.6	-39.54	-63.36	-8.04	78.9
2.88	1.706	1.305	.479	646.2	244.4	349.7	188.8	.831	.310	561.4	525.5	521.0	-39.54	-57.32	-1.62	77.8
2.92	1.702	1.301	.477	646.2	264.0	341.0	206.3	.850	.278	561.4	525.1	521.4	-39.54	-52.76	9.90	77.7

MASS FLOW RATE (VENA CONTRACTA) -- 2.011

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	310.5	362.4	.857	.266	1.054	79.4	82.7
RIGHT SIDE	300.8	351.7	.855	.269	1.051	79.5	83.1

TABLE E10 (CONTINUED)

RUN 3 CLEARANCE - .057 RPM - 7507.

R2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.302	1.072	.257	542.6	121.2	232.9	81.7	.934	.128	550.2	544.2	543.5	67.41	-69.46	-21.88	70.1
1.82	1.301	1.072	.256	542.6	130.3	237.2	91.5	.963	.072	550.2	544.0	543.6	67.41	-67.30	-12.78	70.3
1.90	1.301	1.072	.255	542.6	143.1	246.8	102.9	1.008	-.017	550.2	543.6	543.6	67.41	-65.35	-.83	70.6
2.10	1.300	1.070	.252	542.6	130.6	235.4	100.0	.972	.055	550.2	544.1	543.8	67.41	-64.85	15.87	70.3
2.34	1.300	1.071	.253	542.6	97.3	209.8	81.8	.839	.297	550.2	545.3	543.8	67.41	-67.06	23.21	68.8
2.60	1.301	1.071	.255	542.6	57.1	176.2	56.2	.673	.547	550.2	546.8	543.7	67.41	-71.41	24.93	66.4
2.80	1.302	1.072	.257	542.6	104.3	160.4	83.1	.548	.700	550.2	548.6	543.5	67.41	-58.78	-29.40	60.5
2.88	1.301	1.071	.255	542.6	116.4	155.5	92.4	.542	.707	550.2	548.5	543.6	67.41	-53.52	-13.31	60.2
2.92	1.300	1.071	.254	542.6	119.8	151.9	94.9	.538	.711	550.2	548.5	543.7	67.41	-51.33	-.72	60.2
1.78	1.302	1.072	.256	542.6	124.9	239.7	82.9	.960	.078	550.2	544.0	543.6	67.41	-69.76	-20.18	70.5
1.82	1.301	1.071	.255	542.6	133.6	243.5	91.4	.989	.021	550.2	543.8	543.6	67.41	-67.94	-12.55	70.7
1.90	1.300	1.070	.252	542.6	138.7	244.1	99.1	1.013	-.026	550.2	543.7	543.8	67.41	-66.04	-2.09	70.8
2.10	1.299	1.069	.250	542.6	131.8	235.4	96.1	.993	.014	550.2	544.0	543.9	67.41	-65.92	17.60	70.7
2.34	1.300	1.070	.252	542.6	102.9	216.4	81.1	.877	.230	550.2	545.0	543.8	67.41	-67.99	21.54	69.5
2.60	1.301	1.071	.254	542.6	74.1	192.8	70.1	.740	.452	550.2	546.3	543.7	67.41	-68.67	19.76	67.3
2.80	1.301	1.071	.255	542.6	93.2	174.9	83.0	.609	.629	550.2	548.0	543.7	67.41	-61.66	-17.52	62.4
2.88	1.300	1.071	.254	542.6	104.3	164.4	89.8	.583	.660	550.2	548.1	543.7	67.41	-56.89	-2.97	61.8
2.92	1.300	1.071	.253	542.6	108.5	158.9	92.6	.572	.673	550.2	548.1	543.8	67.41	-54.33	7.97	61.7

MASS FLOW RATE (VENA CONTRACTA) -- 1.358

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	205.3	260.6	.788	.379	.683	54.5	67.0
RIGHT SIDE	209.8	257.4	.815	.336	.710	54.6	67.6

RUN 3 CLEARANCE - .057 RPM - 10060.

R2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.300	1.093	.332	513.5	57.2	203.5	53.2	1.072	-.149	553.6	540.0	540.4	46.24	-74.86	-24.72	85.0
1.82	1.300	1.093	.331	513.5	61.4	197.3	58.5	1.072	-.149	553.6	540.1	540.4	46.24	-72.76	-13.73	84.8
1.90	1.300	1.093	.332	513.5	68.0	198.0	65.4	1.081	-.169	553.6	540.0	540.4	46.24	-70.72	-1.88	84.7
2.10	1.300	1.094	.332	513.5	74.5	199.3	74.3	1.019	-.038	553.6	540.3	540.4	46.24	-68.10	5.99	83.7
2.34	1.300	1.094	.333	513.5	74.6	192.7	71.2	.894	.201	553.6	541.2	540.3	46.24	-68.30	5.99	81.6
2.60	1.301	1.094	.334	513.5	82.3	188.0	62.8	.766	.413	553.6	542.4	540.2	46.24	-70.48	-2.85	78.3
2.80	1.302	1.095	.336	513.5	136.8	186.1	92.6	.668	.553	553.6	543.7	540.1	46.24	-60.17	-21.52	72.4
2.88	1.301	1.094	.334	513.5	153.4	183.5	105.8	.671	.550	553.6	543.8	540.3	46.24	-54.78	-11.09	71.7
2.92	1.299	1.093	.330	513.5	162.0	178.3	111.7	.675	.544	553.6	543.7	540.5	46.24	-51.19	.12	71.6
1.78	1.299	1.093	.331	513.5	56.6	211.4	55.6	1.033	-.066	553.6	540.3	540.5	46.24	-74.76	-33.50	84.4
1.82	1.299	1.093	.331	513.5	61.6	203.8	60.5	1.045	-.092	553.6	540.2	540.5	46.24	-72.73	-22.50	84.5
1.90	1.299	1.093	.331	513.5	66.9	198.5	65.9	1.056	-.114	553.6	540.2	540.5	46.24	-70.61	-9.00	84.4
2.10	1.299	1.093	.330	513.5	67.4	191.0	67.2	1.033	-.067	553.6	540.3	540.5	46.24	-69.41	11.60	84.0
2.34	1.300	1.093	.331	513.5	63.2	184.8	61.7	.923	.149	553.6	541.0	540.5	46.24	-70.50	17.42	82.5
2.60	1.301	1.094	.334	513.5	74.6	191.4	61.0	.800	.361	553.6	542.0	540.3	46.24	-71.43	3.91	79.3
2.80	1.302	1.095	.336	513.5	120.5	192.1	84.9	.701	.508	553.6	543.4	540.1	46.24	-63.77	-12.14	74.2
2.88	1.301	1.094	.333	513.5	142.0	184.1	99.4	.687	.528	553.6	543.5	540.3	46.24	-57.33	-3.69	72.9
2.92	1.299	1.092	.329	513.5	151.9	173.0	105.9	.685	.531	553.6	543.4	540.6	46.24	-52.27	10.78	73.0

MASS FLOW RATE (VENA CONTRACTA) -- 1.276

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	190.9	236.0	.809	.346	.655	59.2	79.1
RIGHT SIDE	189.8	230.3	.824	.320	.608	59.3	79.8

RUN 3 CLEARANCE - .057 RPM - 12150.

R2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.299	1.127	.447	466.5	52.2	160.3	29.5	1.049	-.100	557.9	539.2	539.3	-25.64	-79.39	-13.50	88.3
1.82	1.299	1.127	.447	466.5	57.3	158.8	35.3	1.053	-.110	557.9	539.2	539.3	-25.64	-77.18	-8.00	88.2
1.90	1.299	1.127	.447	466.5	69.1	156.3	44.2	1.004	-.008	557.9	539.4	539.3	-25.64	-73.56	-1.78	87.5
2.10	1.299	1.127	.447	466.5	88.0	156.9	52.5	.893	.203	557.9	539.9	539.3	-25.64	-70.46	4.76	85.6
2.34	1.299	1.127	.447	466.5	99.2	170.3	56.4	.837	.300	557.9	540.4	539.4	-25.64	-70.67	6.59	83.9
2.60	1.299	1.127	.447	466.5	113.2	187.2	58.0	.771	.406	557.9	541.3	539.3	-25.64	-71.97	.46	81.0
2.80	1.300	1.127	.448	466.5	159.5	212.5	100.4	.748	.441	557.9	542.3	539.3	-25.64	-61.81	-16.06	76.2
2.88	1.299	1.126	.447	466.5	185.9	219.1	126.8	.768	.410	557.9	542.2	539.4	-25.64	-54.66	-10.61	74.7
2.92	1.295	1.123	.440	466.5	198.5	215.1	137.4	.801	.358	557.9	542.0	539.8	-25.64	-50.29	.99	75.0
1.78	1.299	1.127	.447	466.5	39.6	193.2	15.2	1.028	-.056	557.9	539.2	539.3	-25.64	-85.48	-31.00	88.5
1.82	1.298	1.126	.447	466.5	39.6	200.8	20.9	1.046	-.094	557.9	539.1	539.4	-25.64	-84.03	-31.00	88.8
1.90	1.299	1.127	.447	466.5	55.6	178.7	36.6	1.040	-.082	557.9	539.2	539.4	-25.64	-78.17	-12.76	88.2
2.10	1.299	1.126	.447	466.5	80.5	156.4	53.6	.983	.033	557.9	539.5	539.4	-25.64	-69.95	13.12	86.9
2.34	1.298	1.126	.446	466.5	96.3	162.6	60.6	.894	.201	557.9	540.0	539.4	-25.64	-68.12	18.34	85.2
2.60	1.299	1.127	.447	466.5	109.6	180.2	63.5	.813	.339	557.9	540.8	539.4	-25.64	-69.37	14.73	82.6
2.80	1.299	1.127	.447	466.5	140.8	214.0	91.2	.789	.378	557.9	541.7	539.3	-25.64	-64.77	-3.33	78.8
2.88	1.297	1.125	.445	466.5	168.1	217.6	116.8	.802	.357	557.9	541.7	539.5	-25.64	-57.55	.71	77.3
2.92	1.296	1.124	.442	466.5	183.3	210.5	129.6	.821	.326	557.9	541.5	539.7	-25.64	-52.01	11.84	77.1

MASS FLOW RATE (VENA CONTRACTA) -- 1.183

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	191.4	241.1	.794	.370	.597	51.7	81.1
RIGHT SIDE	190.1	227.2	.837	.300	.576	51.7	82.8

TABLE E10 (CONTINUED)

RUN 3 CLEARANCE - .057 RPM - 12080.

R2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.546	1.153	.314	669.6	97.8	270.8	76.6	1.002	-.003	551.0	531.2	531.1	54.66	-73.57	-12.95	81.9
1.82	1.546	1.153	.314	669.6	103.8	268.7	87.3	.999	.003	551.0	531.2	531.2	54.66	-71.05	-6.96	81.7
1.90	1.546	1.154	.314	669.6	112.9	277.2	95.3	1.019	-.039	551.0	530.9	531.1	54.66	-69.90	.47	81.8
2.10	1.546	1.154	.315	669.6	112.4	277.4	102.7	.986	.027	551.0	531.3	531.1	54.66	-68.28	10.70	81.2
2.34	1.548	1.155	.316	669.6	99.0	265.1	98.4	.879	.228	551.0	532.7	531.0	54.66	-68.22	12.69	79.4
2.60	1.550	1.156	.318	669.6	89.6	252.3	82.1	.749	.440	551.0	534.9	530.7	54.66	-71.00	-.40	76.1
2.80	1.552	1.158	.320	669.6	166.2	237.4	121.5	.631	.602	551.0	537.7	530.5	54.66	-59.21	-24.01	69.7
2.88	1.549	1.156	.317	669.6	181.8	233.0	134.7	.634	.598	551.0	537.6	530.8	54.66	-54.68	-9.88	69.4
2.92	1.546	1.154	.314	669.6	187.1	226.9	138.2	.635	.596	551.0	537.5	531.1	54.66	-52.47	2.00	69.6
1.78	1.547	1.154	.315	669.6	107.7	281.4	88.0	1.015	-.030	551.0	530.9	531.0	54.66	-71.78	-14.75	81.9
1.82	1.546	1.154	.314	669.6	109.4	279.7	91.5	1.015	-.031	551.0	530.9	531.1	54.66	-70.90	-10.60	81.8
1.90	1.546	1.153	.314	669.6	109.9	277.8	93.6	1.014	-.028	551.0	531.0	531.1	54.66	-70.31	-3.17	81.8
2.10	1.546	1.154	.314	669.6	105.9	259.2	97.1	.960	.079	551.0	531.6	531.1	54.66	-68.01	19.27	81.0
2.34	1.548	1.155	.316	669.6	94.5	248.2	94.5	.837	.299	551.0	533.2	530.9	54.66	-67.63	15.65	78.8
2.60	1.550	1.156	.318	669.6	87.3	250.3	82.6	.761	.421	551.0	534.6	530.8	54.66	-70.74	8.01	76.7
2.80	1.552	1.158	.320	669.6	151.0	251.3	119.0	.672	.548	551.0	536.9	530.5	54.66	-61.75	-15.96	71.3
2.88	1.549	1.156	.317	669.6	172.5	241.1	134.8	.665	.558	551.0	537.0	530.8	54.66	-56.00	-3.31	70.7
2.92	1.547	1.154	.315	669.6	179.7	232.0	141.2	.665	.558	551.0	536.7	531.1	54.66	-52.50	10.68	70.9

MASS FLOW RATE (VENA CONTRACTA) -- 1.870

MASS FLOW RATE AVERAGED OUTPUT

	R2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	257.0	324.4	.792	.372	.887	68.4	76.6
RIGHT SIDE	253.8	320.5	.792	.373	.871	68.4	76.9

RUN 3 CLEARANCE - .057 RPM - 14820.

R2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.551	1.208	.416	620.5	75.6	225.4	69.0	.962	.074	557.6	528.6	528.2	1.72	-72.16	-13.94	87.2
1.82	1.550	1.208	.416	620.5	78.0	224.1	71.7	.969	.062	557.6	528.6	528.3	1.72	-71.34	-7.21	87.2
1.90	1.551	1.209	.416	620.5	85.1	231.3	78.9	.967	.064	557.6	528.6	528.2	1.72	-70.06	-3.40	87.0
2.10	1.551	1.209	.417	620.5	103.3	242.8	89.4	.902	.186	557.6	529.3	528.2	1.72	-68.39	-5.46	85.5
2.34	1.552	1.210	.417	620.5	111.3	244.8	85.0	.828	.314	557.6	530.4	528.1	1.72	-69.68	1.20	83.6
2.60	1.553	1.210	.418	620.5	116.8	260.9	74.7	.777	.396	557.6	531.8	528.0	1.72	-73.35	-3.21	81.4
2.80	1.556	1.212	.420	620.5	194.3	303.9	147.9	.775	.399	557.6	532.9	527.7	1.72	-60.87	-25.69	76.6
2.88	1.552	1.210	.417	620.5	233.3	298.2	178.7	.776	.398	557.6	533.0	528.1	1.72	-53.18	-14.92	74.8
2.92	1.545	1.204	.411	620.5	247.2	287.9	188.2	.796	.367	557.6	532.8	528.8	1.72	-49.17	-.35	75.0
1.78	1.550	1.209	.418	618.8	82.7	195.8	62.6	.848	.282	557.8	529.6	528.3	.85	-71.36	-6.50	85.8
1.82	1.549	1.209	.418	618.8	81.6	203.6	65.7	.876	.232	557.8	529.4	528.3	.85	-71.18	-4.00	86.1
1.90	1.549	1.209	.418	618.8	84.2	215.1	71.4	.901	.187	557.8	529.3	528.3	.85	-70.61	-1.27	86.2
2.10	1.550	1.210	.419	618.8	98.9	227.3	85.5	.895	.199	557.8	529.4	528.2	.85	-67.91	7.80	85.7
2.34	1.551	1.211	.420	618.8	112.5	223.1	82.8	.796	.366	557.8	530.5	528.1	.85	-68.22	13.24	83.5
2.60	1.552	1.211	.421	618.8	120.5	239.0	74.2	.745	.445	557.8	531.9	528.0	.85	-71.92	9.71	81.2
2.80	1.555	1.213	.422	618.8	174.6	290.4	129.8	.766	.413	557.8	532.8	527.8	.85	-63.46	-10.00	77.8
2.88	1.551	1.211	.420	618.8	208.3	293.4	160.9	.783	.387	557.8	532.7	528.1	.85	-56.74	-3.52	76.7
2.92	1.547	1.207	.416	618.8	225.8	279.6	174.5	.794	.370	557.8	532.4	528.5	.85	-51.37	10.94	76.7

MASS FLOW RATE (VENA CONTRACTA) -- 1.764

MASS FLOW RATE AVERAGED OUTPUT

	R2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	268.6	331.6	.810	.344	.895	68.6	81.4
RIGHT SIDE	253.7	320.0	.793	.371	.847	68.7	81.8

RUN 3 CLEARANCE - .057 RPM - 18460.

R2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.549	1.284	.557	539.6	48.3	282.5	.0	2.211	-3.889	564.5	524.3	529.5	-67.45	-90.00	-30.19	92.9
1.82	1.549	1.284	.556	539.6	48.8	293.5	5.9	1.915	-2.666	564.5	524.4	529.5	-67.45	-88.84	-32.71	92.8
1.90	1.548	1.283	.556	539.6	66.1	294.4	27.1	1.683	-1.833	564.5	525.0	529.6	-67.45	-84.72	-32.00	91.8
2.10	1.550	1.285	.557	539.6	131.8	257.6	84.4	1.575	-1.481	564.5	526.2	529.4	-67.45	-70.88	-4.77	88.3
2.34	1.549	1.285	.557	539.6	180.2	246.5	105.4	1.184	-.401	564.5	528.1	529.5	-67.45	-64.68	6.04	83.8
2.60	1.548	1.284	.556	539.6	190.5	272.4	100.4	.971	.057	564.5	530.0	529.6	-67.45	-68.38	2.84	80.6
2.80	1.548	1.283	.556	539.6	255.2	300.0	150.0	.855	.269	564.5	532.4	529.6	-67.45	-60.00	-11.34	73.7
2.88	1.542	1.279	.552	539.6	278.9	312.2	179.3	.905	.180	564.5	532.0	530.2	-67.45	-54.95	-3.97	73.4
2.92	1.536	1.274	.549	539.6	288.2	317.5	192.9	.959	.081	564.5	531.5	530.8	-67.45	-52.60	2.98	74.0
1.78	1.548	1.286	.559	537.8	23.7	316.0	.0	2.024	-3.098	564.7	523.3	529.6	-67.68	-90.00	-27.39	94.6
1.82	1.548	1.286	.559	537.8	23.7	322.5	.0	1.900	-2.611	564.7	523.4	529.6	-67.68	-90.00	-27.39	94.5
1.90	1.548	1.286	.559	537.8	24.1	351.2	8.3	1.592	-1.534	564.7	523.4	529.6	-67.68	-88.65	-33.50	94.5
2.10	1.549	1.286	.560	537.8	93.8	287.8	57.5	1.510	-1.279	564.7	525.7	529.5	-67.68	-78.48	-9.86	90.1
2.34	1.549	1.286	.559	537.8	158.0	253.0	100.7	1.366	-.865	564.7	527.1	529.6	-67.68	-66.54	12.72	86.1
2.60	1.548	1.285	.559	537.8	185.4	267.1	109.5	1.062	-.127	564.7	529.0	529.6	-67.68	-65.80	14.06	82.4
2.80	1.547	1.285	.559	537.8	230.2	302.0	143.6	.927	.141	564.7	531.0	529.7	-67.68	-61.60	3.04	77.3
2.88	1.544	1.282	.557	537.8	255.4	304.2	168.2	.951	.095	564.7	530.9	530.0	-67.68	-56.43	10.14	76.4
2.92	1.541	1.280	.555	537.8	265.9	304.1	181.4	.997	.007	564.7	530.4	530.3	-67.68	-53.39	17.25	76.7

MASS FLOW RATE (VENA CONTRACTA) -- 1.585

MASS FLOW RATE AVERAGED OUTPUT

	R2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	281.1	283.0	.993	.014	.920	57.2	80.3
RIGHT SIDE	283.1	267.1	1.060	-.123	.843	57.2	82.4

TABLE E10 (CONTINUED)

RUN 3 CLEARANCE - .057 RPM - 12866.

W2	PT0/P2	P1/P2	DR	V1	V2	W2	VN2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.704	1.186	.303	737.5	174.0	344.9	124.0	.998	.004	536.4	519.3	515.2	61.04	-68.92	-12.02	77.7
1.82	1.703	1.185	.302	737.5	183.9	349.0	133.2	1.020	-.041	536.4	515.0	515.3	61.04	-67.57	-4.83	77.9
1.90	1.702	1.184	.301	737.5	186.2	351.5	138.4	1.028	-.057	536.4	514.9	515.4	61.04	-66.02	1.72	78.0
2.10	1.701	1.183	.301	737.5	160.6	332.7	125.9	.961	.077	536.4	516.3	515.5	61.04	-67.83	14.94	77.2
2.34	1.704	1.185	.303	737.5	116.0	305.1	98.0	.844	.287	536.4	518.4	515.2	61.04	-71.26	23.12	75.7
2.60	1.708	1.188	.305	737.5	97.7	319.4	97.4	.770	.407	536.4	520.8	514.9	61.04	-72.23	-25.46	72.9
2.80	1.709	1.189	.306	737.5	184.2	283.1	163.2	.658	.567	536.4	523.6	514.8	61.04	-54.80	-23.82	67.0
2.88	1.704	1.186	.303	737.5	192.6	280.6	171.0	.667	.555	536.4	523.4	515.2	61.04	-52.46	-9.04	67.2
2.92	1.702	1.184	.301	737.5	193.2	277.8	172.1	.672	.548	536.4	523.3	515.4	61.04	-51.71	2.00	67.5
1.78	1.704	1.187	.305	736.1	188.4	358.8	134.2	1.025	-.058	536.6	514.7	515.1	60.94	-68.04	-11.00	78.0
1.82	1.702	1.186	.304	736.1	190.8	358.4	135.4	1.036	-.074	536.6	514.6	515.3	60.94	-67.81	-4.91	78.1
1.90	1.702	1.185	.304	736.1	190.2	353.0	141.3	1.026	-.053	536.6	514.9	515.3	60.94	-66.40	3.31	77.9
2.10	1.701	1.185	.303	736.1	167.6	334.8	127.2	.970	.059	536.6	516.1	515.4	60.94	-67.67	17.00	77.3
2.34	1.704	1.187	.305	736.1	127.6	307.4	104.5	.857	.265	536.6	518.1	515.2	60.94	-70.12	24.52	75.9
2.60	1.708	1.190	.308	736.1	100.5	322.4	99.1	.781	.390	536.6	520.4	514.8	60.94	-72.09	-13.63	73.3
2.80	1.710	1.191	.309	736.1	183.7	277.5	161.3	.642	.587	536.6	523.8	514.6	60.94	-54.47	-15.84	66.7
2.88	1.704	1.187	.306	736.1	190.6	275.8	169.2	.657	.568	536.6	523.5	515.1	60.94	-52.16	-1.95	67.2
2.92	1.703	1.186	.305	736.1	192.9	272.9	173.4	.665	.558	536.6	523.1	515.2	60.94	-50.55	10.30	67.6

MASS FLOW RATE (VENA CONTRACTA) -- 2.257

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	312.7	387.4	.807	.349	1.092	66.7	73.1
RIGHT SIDE	313.3	387.3	.809	.345	1.131	66.6	73.2

RUN 3 CLEARANCE - .057 RPM - 15420.

W2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.701	1.257	.412	677.9	92.4	254.1	90.6	.828	.315	546.1	514.2	511.6	16.61	-69.12	-14.08	84.4
1.82	1.701	1.257	.412	677.9	94.0	255.7	92.6	.834	.304	546.1	514.1	511.6	16.61	-68.77	-8.81	84.5
1.90	1.702	1.258	.412	677.9	97.1	265.5	95.6	.841	.293	546.1	514.1	511.6	16.61	-68.89	-8.00	84.4
2.10	1.703	1.258	.413	677.9	110.3	280.0	106.0	.829	.313	546.1	514.6	511.5	16.61	-67.76	-6.33	83.5
2.34	1.703	1.258	.413	677.9	111.3	271.1	94.1	.755	.429	546.1	516.2	511.5	16.61	-69.68	1.22	81.5
2.60	1.704	1.259	.414	677.9	112.8	294.0	85.9	.741	.450	546.1	517.4	511.4	16.61	-73.01	-4.04	79.9
2.80	1.709	1.263	.416	677.9	210.9	324.9	166.6	.721	.481	546.1	519.2	511.0	16.61	-59.15	-26.37	74.1
2.88	1.703	1.259	.413	677.9	252.2	317.9	198.7	.722	.479	546.1	519.2	511.5	16.61	-51.30	-14.05	72.5
2.92	1.694	1.252	.407	677.9	265.5	311.8	209.8	.743	.448	546.1	518.9	512.3	16.61	-47.71	-.38	73.0
1.78	1.701	1.258	.414	676.4	95.3	251.1	89.7	.787	.381	546.3	514.9	511.6	16.01	-69.06	-17.47	83.5
1.82	1.701	1.258	.414	676.4	99.1	263.9	95.3	.812	.340	546.3	514.7	511.7	16.01	-68.84	-18.45	83.7
1.90	1.702	1.259	.415	676.4	104.8	277.3	102.2	.833	.306	546.3	514.4	511.6	16.01	-68.37	-16.48	83.8
2.10	1.702	1.259	.415	676.4	113.3	262.0	105.8	.788	.378	546.3	515.1	511.6	16.01	-66.19	1.50	82.8
2.34	1.703	1.260	.415	676.4	114.2	246.8	89.7	.702	.507	546.3	516.7	511.5	16.01	-68.68	9.54	80.7
2.60	1.704	1.260	.416	676.4	117.1	276.1	82.8	.704	.504	546.3	517.9	511.4	16.01	-72.54	2.46	79.2
2.80	1.710	1.265	.420	676.4	191.2	332.6	160.0	.748	.441	546.3	518.1	510.8	16.01	-61.25	-12.84	76.1
2.88	1.705	1.261	.417	676.4	232.2	329.2	192.9	.751	.436	546.3	518.3	511.3	16.01	-54.12	-5.58	74.5
2.92	1.700	1.258	.414	676.4	249.5	312.7	204.4	.749	.439	546.3	518.1	511.7	16.01	-49.20	8.71	74.3

MASS FLOW RATE (VENA CONTRACTA) -- 2.108

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	295.1	391.8	.753	.432	1.048	68.6	79.0
RIGHT SIDE	291.5	389.7	.748	.440	1.040	68.5	79.4

RUN 3 CLEARANCE - .057 RPM - 18890.

W2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.703	1.333	.521	611.7	103.9	237.5	60.5	1.260	-.588	552.3	509.3	511.0	-58.36	-75.25	-14.94	89.0
1.82	1.703	1.333	.521	611.7	115.2	234.3	70.9	1.251	-.564	552.3	509.5	511.1	-58.36	-72.38	-10.24	88.6
1.90	1.703	1.333	.521	611.7	132.7	230.8	84.6	1.199	-.438	552.3	509.7	511.1	-58.36	-68.50	-2.84	87.8
2.10	1.703	1.333	.521	611.7	157.6	244.2	100.9	1.044	-.090	552.3	510.7	511.0	-58.36	-65.60	2.00	85.9
2.34	1.702	1.333	.521	611.7	164.5	273.0	105.8	.972	.055	552.3	511.5	511.1	-58.36	-67.21	5.89	84.7
2.60	1.704	1.334	.522	611.7	173.1	303.1	99.8	.872	.240	552.3	513.4	510.9	-58.36	-70.78	.73	82.0
2.80	1.705	1.335	.522	611.7	248.8	321.4	153.2	.784	.386	552.3	516.3	510.8	-58.36	-61.53	-12.36	75.2
2.88	1.698	1.329	.519	611.7	278.6	333.7	187.1	.822	.324	552.3	515.9	511.5	-58.36	-55.89	-5.79	74.6
2.92	1.691	1.324	.515	611.7	291.3	338.4	204.5	.868	.246	552.3	515.2	512.1	-58.36	-52.82	3.18	75.2
1.78	1.702	1.336	.526	608.7	67.5	285.5	29.4	1.170	-.369	552.6	509.3	511.1	-58.92	-84.09	-26.10	89.7
1.82	1.702	1.336	.526	608.7	80.8	271.2	44.9	1.184	-.401	552.6	509.4	511.1	-58.92	-80.46	-18.30	89.4
1.90	1.702	1.336	.526	608.7	104.8	252.3	67.1	1.183	-.399	552.6	509.6	511.1	-58.92	-74.58	-5.72	88.7
2.10	1.702	1.336	.526	608.7	141.9	237.5	94.6	1.117	-.248	552.6	510.2	511.1	-58.92	-66.52	12.16	87.0
2.34	1.702	1.336	.526	608.7	163.0	260.2	108.7	.991	.018	552.6	511.2	511.1	-58.92	-65.31	14.89	85.1
2.60	1.704	1.338	.527	608.7	178.6	290.8	110.9	.878	.230	552.6	513.1	510.9	-58.92	-67.57	10.75	82.2
2.80	1.704	1.337	.527	608.7	233.9	321.9	150.3	.811	.342	552.6	515.5	510.9	-58.92	-62.15	-1.20	77.0
2.88	1.700	1.334	.525	608.7	259.3	323.8	176.8	.834	.305	552.6	515.2	511.3	-58.92	-56.90	7.56	76.4
2.92	1.697	1.332	.523	608.7	268.3	324.3	189.1	.863	.256	552.6	514.6	511.5	-58.92	-54.33	14.73	76.9

MASS FLOW RATE (VENA CONTRACTA) -- 1.965

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	293.6	333.7	.880	.226	1.072	65.8	81.5
RIGHT SIDE	289.0	323.5	.894	.201	1.032	65.8	82.4

TABLE E10 (CONTINUED)

RUN 5 CLEARANCE - .052 RPM - 10144.

R2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.302	1.096	.338	506.3	49.3	195.5	48.3	1.054	-.111	539.7	526.0	526.3	43.18	-75.69	-28.21	85.3
1.82	1.302	1.096	.338	506.3	55.1	189.3	54.6	1.054	-.110	539.7	526.1	526.3	43.18	-73.25	-16.90	85.1
1.90	1.302	1.096	.338	506.3	60.0	190.9	59.4	1.066	-.136	539.7	526.0	526.3	43.18	-71.87	-6.70	85.2
2.10	1.303	1.096	.339	506.3	69.1	193.5	68.8	.994	.011	539.7	526.3	526.2	43.18	-69.16	-1.68	84.0
2.34	1.303	1.097	.340	506.3	73.2	192.0	67.9	.890	.209	539.7	527.0	526.2	43.18	-69.30	.22	82.0
2.60	1.304	1.098	.342	506.3	81.3	187.4	58.3	.765	.415	539.7	528.2	526.1	43.18	-71.89	-6.33	78.7
2.80	1.304	1.097	.341	506.3	126.3	187.8	85.5	.700	.510	539.7	529.2	526.1	43.18	-62.92	-16.59	74.4
2.88	1.303	1.096	.339	506.3	146.1	185.4	101.1	.698	.513	539.7	529.3	526.3	43.18	-56.93	-8.08	73.3
2.92	1.301	1.095	.335	506.3	157.5	177.4	107.0	.689	.525	539.7	529.4	526.5	43.18	-52.88	2.00	72.7
1.78	1.302	1.097	.342	505.0	53.7	207.4	53.3	1.014	-.028	539.8	526.2	526.2	42.81	-75.11	-33.50	84.8
1.82	1.303	1.097	.342	505.0	60.0	197.3	59.7	1.018	-.035	539.8	526.1	526.2	42.81	-72.39	-20.50	84.7
1.90	1.303	1.097	.342	505.0	64.5	195.0	64.1	1.029	-.058	539.8	526.1	526.2	42.81	-70.80	-9.37	84.7
2.10	1.303	1.097	.342	505.0	68.2	192.1	68.2	1.003	-.006	539.8	526.2	526.2	42.81	-69.20	6.72	84.2
2.34	1.303	1.098	.343	505.0	67.9	187.6	65.3	.907	.177	539.8	526.8	526.2	42.81	-69.62	12.72	82.7
2.60	1.304	1.098	.345	505.0	75.9	191.3	59.7	.790	.376	539.8	527.9	526.0	42.81	-71.83	1.50	79.6
2.80	1.305	1.099	.347	505.0	124.1	197.7	91.0	.719	.483	539.8	529.0	525.9	42.81	-62.57	-12.03	74.8
2.88	1.304	1.098	.345	505.0	147.4	188.0	106.0	.698	.512	539.8	529.2	526.1	42.81	-55.67	-2.77	73.2
2.92	1.303	1.097	.342	505.0	156.0	180.5	112.6	.702	.507	539.8	529.1	526.2	42.81	-51.39	9.62	73.3

MASS FLOW RATE (VENA CONTRACTA) -- 1.297

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	189.1	232.4	.814	.338	.636	72.2	79.6
RIGHT SIDE	191.6	233.9	.819	.329	.650	72.1	79.9

RUN 5 CLEARANCE - .052 RPM - 14824.

R2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.555	1.212	.421	608.1	75.2	202.0	66.3	1.039	-.080	536.9	507.9	508.1	-4.94	-70.85	3.73	88.1
1.82	1.555	1.212	.421	608.1	78.1	206.8	68.9	1.029	-.059	536.9	508.0	508.1	-4.94	-70.53	3.60	88.0
1.90	1.555	1.213	.421	608.1	83.2	223.8	73.5	1.002	-.004	536.9	508.1	508.1	-4.94	-70.83	-4.46	87.6
2.10	1.556	1.213	.422	608.1	102.3	231.3	85.8	.936	.123	536.9	508.7	508.0	-4.94	-68.23	1.10	86.2
2.34	1.556	1.213	.422	608.1	111.0	247.5	84.0	.868	.247	536.9	509.7	508.0	-4.94	-70.16	-2.52	84.4
2.60	1.557	1.214	.422	608.1	112.6	262.6	71.8	.814	.337	536.9	510.9	507.9	-4.94	-74.14	-2.85	82.6
2.80	1.558	1.215	.423	608.1	183.7	301.6	138.2	.802	.357	536.9	512.1	507.8	-4.94	-62.73	-24.07	78.1
2.88	1.554	1.212	.421	608.1	219.3	296.5	168.0	.808	.348	536.9	512.0	508.1	-4.94	-55.49	-11.98	76.8
2.92	1.548	1.207	.415	608.1	237.6	284.4	181.1	.828	.314	536.9	511.8	508.8	-4.94	-50.44	4.11	76.7
1.78	1.555	1.215	.425	606.2	84.9	193.6	64.1	.896	.198	537.1	508.9	508.0	-5.99	-70.67	-5.67	86.5
1.82	1.555	1.215	.425	606.2	87.0	197.1	69.5	.918	.157	537.1	508.7	508.0	-5.99	-69.36	-.98	86.7
1.90	1.555	1.215	.425	606.2	88.4	208.3	74.9	.946	.105	537.1	508.5	508.0	-5.99	-68.93	3.10	86.9
2.10	1.556	1.215	.425	606.2	92.9	238.8	79.8	.934	.128	537.1	508.7	507.9	-5.99	-70.48	-.71	86.4
2.34	1.556	1.216	.426	606.2	93.2	255.3	71.4	.879	.228	537.1	509.6	507.9	-5.99	-73.76	-1.64	85.1
2.60	1.557	1.216	.426	606.2	117.5	251.4	78.0	.798	.364	537.1	510.9	507.8	-5.99	-71.92	6.67	82.4
2.80	1.562	1.220	.430	606.2	183.3	296.9	141.6	.794	.370	537.1	511.8	507.4	-5.99	-61.51	-10.44	78.2
2.88	1.562	1.220	.430	606.2	228.3	289.9	174.9	.773	.402	537.1	512.0	507.4	-5.99	-52.90	-3.80	75.4
2.92	1.554	1.214	.424	606.2	235.9	289.0	187.4	.832	.308	537.1	511.2	508.1	-5.99	-49.58	10.04	77.1

MASS FLOW RATE (VENA CONTRACTA) -- 1.795

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	265.5	315.4	.842	.291	.899	77.0	82.2
RIGHT SIDE	264.3	320.5	.825	.320	.903	76.7	82.1

RUN 5 CLEARANCE - .052 RPM - 16050.

R2	PT0/P2	P1/P2	DR	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	BETA1	BETA2	THETA	ETA(L)
1.78	1.705	1.263	.419	671.0	101.3	263.7	98.7	.996	.008	539.9	505.1	505.0	1.22	-68.01	-15.43	87.4
1.82	1.704	1.262	.418	671.0	98.3	272.1	97.0	1.021	-.042	539.9	504.9	505.1	1.22	-69.13	-13.46	87.9
1.90	1.705	1.263	.419	671.0	103.3	276.4	100.7	.993	.013	539.9	505.1	505.0	1.22	-68.63	-12.30	87.4
2.10	1.706	1.264	.419	671.0	113.6	285.9	105.3	.929	.136	539.9	506.1	504.9	1.22	-68.39	-12.34	85.9
2.34	1.706	1.264	.420	671.0	116.8	296.0	98.8	.868	.247	539.9	507.3	504.9	1.22	-70.49	-11.68	84.2
2.60	1.707	1.265	.421	671.0	119.8	315.7	89.0	.820	.327	539.9	508.9	504.8	1.22	-73.62	-16.19	82.2
2.80	1.709	1.266	.421	671.0	206.9	351.6	171.6	.826	.318	539.9	509.4	504.7	1.22	-60.79	-25.06	78.5
2.88	1.704	1.263	.419	671.0	253.3	340.9	205.9	.818	.332	539.9	509.8	505.0	1.22	-52.84	-13.39	76.2
2.92	1.697	1.257	.414	671.0	271.2	327.0	216.0	.822	.324	539.9	509.9	505.7	1.22	-48.66	-.47	75.7
1.78	1.704	1.265	.422	669.0	103.2	248.0	96.0	.920	.154	540.1	506.0	505.0	.26	-67.23	-11.16	86.4
1.82	1.705	1.265	.422	669.0	104.4	258.3	99.5	.945	.107	540.1	505.7	505.0	.26	-67.35	-9.67	86.7
1.90	1.704	1.265	.422	669.0	104.6	269.6	99.7	.946	.105	540.1	505.7	505.0	.26	-68.29	-10.29	86.6
2.10	1.707	1.267	.424	669.0	124.2	289.7	117.6	.931	.133	540.1	505.9	504.8	.26	-66.05	-6.89	85.8
2.34	1.707	1.267	.424	669.0	120.4	275.6	96.4	.819	.330	540.1	507.9	504.8	.26	-69.51	-1.64	83.4
2.60	1.706	1.266	.423	669.0	118.4	305.2	91.8	.824	.322	540.1	508.6	504.8	.26	-72.51	-1.17	82.7
2.80	1.715	1.273	.429	669.0	209.8	345.9	175.6	.808	.347	540.1	509.3	504.1	.26	-59.49	-13.24	78.0
2.88	1.713	1.272	.427	669.0	253.1	345.4	211.3	.812	.341	540.1	509.3	504.2	.26	-52.29	-5.94	76.1
2.92	1.706	1.266	.423	669.0	269.4	335.6	224.9	.836	.302	540.1	508.8	504.8	.26	-47.92	7.46	76.4

MASS FLOW RATE (VENA CONTRACTA) -- 2.099

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	315.1	369.2	.853	.272	1.097	79.0	81.7
RIGHT SIDE	310.4	370.0	.839	.296	1.159	78.8	81.7

AIR TESTS OF ICP RADIAL TURBINE

TABLE E11 OUTPUT DATA OBTAINED USING DISCHARGE PRESSURE AND TEMPERATURE SURVEY

RUN 5 CLEARANCE - .052 RPM - 10144.

R2	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	ETA(L)	PHI
1.78	449.6	49.4	195.5	48.5	1.093	-.194	544.2	529.7	530.2	76.3	.789
1.82	460.8	55.2	189.4	54.7	1.096	-.201	543.4	529.0	529.5	78.0	.809
1.90	475.9	60.1	190.9	59.5	1.109	-.231	542.2	527.9	528.4	80.6	.836
2.10	487.4	69.2	193.5	68.9	1.029	-.058	541.3	527.4	527.6	81.3	.856
2.34	488.1	73.3	192.0	67.9	.914	.164	541.2	528.1	527.5	79.5	.857
2.60	496.5	81.3	187.4	58.3	.781	.390	540.5	528.7	526.8	77.6	.872
2.80	502.5	126.3	187.8	85.5	.712	.492	540.0	529.3	526.4	74.3	.882
2.88	485.2	146.3	185.3	101.2	.710	.496	541.4	530.6	527.8	70.3	.852
2.92	465.3	157.9	177.3	107.3	.702	.507	543.0	532.0	529.3	66.3	.817
1.78	440.9	53.9	207.5	53.5	1.043	-.088	544.9	530.4	530.7	74.5	.776
1.82	451.2	60.2	197.4	59.9	1.051	-.105	544.1	529.6	529.9	76.2	.794
1.90	466.3	64.6	195.0	64.3	1.065	-.135	542.9	528.5	528.9	78.7	.821
2.10	464.0	68.4	192.1	68.4	1.038	-.077	543.1	528.8	529.0	77.9	.817
2.34	462.8	68.1	187.6	65.5	.934	.128	543.2	529.5	529.1	76.1	.815
2.60	475.0	76.0	191.3	59.8	.807	.349	542.3	529.8	528.1	75.0	.836
2.80	481.8	124.3	197.6	91.2	.730	.466	541.7	530.4	527.5	71.4	.848
2.88	472.4	147.7	188.0	106.2	.710	.496	542.5	531.2	528.3	68.3	.832
2.92	448.4	156.6	180.4	113.0	.714	.490	544.3	532.7	530.1	64.3	.789

MASS FLOW RATE (VENA CONTRACTA) -- 1.297

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	189.1	227.0	.833	.306	.636	72.2	76.9
RIGHT SIDE	191.6	228.7	.838	.298	.649	72.1	74.2

RUN 5 CLEARANCE - .052 RPM - 14824.

R2	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	ETA(L)	PHI
1.78	534.2	75.7	201.9	66.7	1.045	-.093	543.9	515.0	515.3	77.6	.781
1.82	538.4	76.5	206.8	69.4	1.037	-.076	543.5	514.6	514.9	78.1	.787
1.90	547.6	83.7	223.7	73.9	1.013	-.026	542.7	513.8	513.9	79.1	.801
2.10	560.0	102.7	231.2	86.2	.949	.100	541.6	513.2	512.7	79.6	.819
2.34	568.2	111.4	247.4	84.3	.878	.229	540.8	513.4	511.9	79.0	.831
2.60	573.3	112.9	262.4	72.0	.822	.324	540.3	514.1	511.3	77.9	.838
2.80	591.9	183.9	301.6	138.4	.810	.344	538.5	513.4	509.4	76.2	.865
2.88	579.3	219.9	296.5	168.4	.815	.336	539.7	514.6	510.9	72.8	.847
2.92	549.6	239.1	284.4	182.1	.832	.307	542.5	517.4	514.5	68.2	.804
1.78	535.5	85.5	193.4	64.5	.900	.190	543.8	515.6	514.8	76.5	.786
1.82	537.9	87.5	197.0	69.9	.924	.146	543.6	515.2	514.6	77.0	.789
1.90	553.6	88.3	208.2	75.2	.959	.080	542.1	513.4	513.1	79.6	.812
2.10	556.5	93.3	238.8	80.2	.944	.108	541.9	513.3	512.8	79.5	.816
2.34	554.7	93.6	235.2	71.7	.885	.216	542.0	514.4	512.9	77.9	.813
2.60	566.5	117.9	251.2	78.3	.805	.352	540.7	514.3	511.5	77.3	.834
2.80	579.6	183.7	296.8	141.9	.801	.359	539.7	514.1	510.0	74.7	.850
2.88	584.7	226.7	299.9	175.2	.780	.391	539.2	514.0	509.5	72.6	.857
2.92	544.1	237.3	289.1	168.5	.835	.302	543.0	517.2	514.1	68.2	.798

MASS FLOW RATE (VENA CONTRACTA) -- 1.795

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	265.5	312.3	.850	.277	.896	77.0	76.9
RIGHT SIDE	264.2	317.6	.832	.308	.900	76.7	76.5

RUN 5 CLEARANCE - .052 RPM - 16050.

R2	V1	V2	W2	VM2	PSI	ZETA(R)	T1	T2	T2P	ETA(L)	PHI
1.78	589.5	102.2	263.8	99.6	.993	.014	548.4	513.5	513.5	77.1	.781
1.82	590.1	99.1	272.3	97.8	1.018	-.037	548.4	513.2	513.5	77.6	.782
1.90	596.6	104.1	276.6	101.5	.993	.013	547.7	512.8	512.7	77.9	.790
2.10	606.9	114.3	285.9	106.0	.932	.131	546.7	512.6	511.6	77.9	.804
2.34	612.9	117.5	295.8	99.4	.871	.242	546.1	513.3	510.9	77.0	.812
2.60	624.1	120.4	315.5	89.5	.824	.321	544.9	513.6	509.6	76.4	.827
2.80	642.2	207.5	351.6	172.0	.832	.308	543.0	512.2	507.7	75.0	.851
2.88	635.9	254.1	340.9	206.6	.823	.322	543.7	513.3	508.7	71.9	.843
2.92	602.4	273.1	327.2	217.5	.824	.321	547.1	517.0	512.8	66.8	.798
1.78	595.6	104.0	248.1	96.7	.919	.155	547.8	513.5	512.6	77.1	.792
1.82	596.5	105.2	258.4	100.2	.945	.106	547.7	513.1	512.5	77.5	.793
1.90	603.7	105.3	269.7	100.4	.949	.100	547.0	512.4	511.7	78.4	.802
2.10	602.2	125.1	289.8	118.4	.933	.130	547.2	512.8	511.7	77.4	.800
2.34	613.5	121.1	275.4	97.0	.822	.325	546.0	513.5	510.5	76.5	.815
2.60	612.5	119.1	305.0	92.3	.826	.318	546.1	514.3	510.7	75.7	.814
2.80	636.7	210.5	345.9	176.1	.813	.339	543.6	512.5	507.4	74.1	.846
2.88	632.6	254.0	345 5	212.0	.817	.333	544.0	512.9	508.0	71.7	.841
2.92	596.2	271.4	335.9	226.6	.836	.301	547.8	516.4	512.4	67.0	.792

MASS FLOW RATE (VENA CONTRACTA) -- 2.099

MASS FLOW RATE AVERAGED OUTPUT

	W2	W2TH	PSI	ZETA	MASS FLOW	ETA(HP)	ETA(T)
LEFT SIDE	315.1	367.5	.858	.265	1.091	79.0	75.4
RIGHT SIDE	310.4	368.5	.842	.291	1.153	78.8	75.2

SCROLL AND GUIDE VANE TESTS OF ICP RADIAL TURBINE

TABLE E12 OUTPUT DATA

PT	PTO/P1	WVC	PHI	ALPH(1)
1	1.18	1.187	.888	80.3
2	1.20	1.260	.889	80.2
3	1.22	1.344	.886	80.1
4	1.24	1.405	.891	80.1
5	1.26	1.484	.890	80.0
6	1.31	1.624	.889	79.9
7	1.35	1.745	.887	79.7
8	1.43	1.990	.888	79.5

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This study was conducted to establish the performance parameters of a radial in-flow, dual discharge turbine and to determine the effect of axial clearance on these parameters. The results of the tests can be utilized for design improvements and for predicting off-design operating conditions.

The air tests of the turbine were made at several total-to-static pressure ratios. The study presents data obtained from measured rotor discharge flow conditions as well as overall turbine conditions. The test turbine is installed at the Propulsion Laboratory of the Naval Postgraduate School, Monterey, California.

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